Synthetic Studies of Sesquiterpenoid Furanoeudesmanes

TSANG Tsun-keung

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Tsang Tsun Keung

Department of Chemistry

The Chinese University of Hong Kong

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ABSTRACT

Tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) were isolated from Japanese stolonifera *Tubipora musica* linnaeus in 1986. They exhibit ichthyotoxicity and cytotoxicity properties. Encouraged by the success in devising efficient syntheses of 3,4-disubstituted furans and precursors **114** and **115** by utilizing a C ring + A ring → AC ring → ABC ring approach in our laboratory, these two approaches are extended to the syntheses of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**).

This thesis reports the synthesis of a key intermediate **137** by utilizing the C ring + A ring → AC ring → ABC ring approach. The initial step involved the formation of a C–C bond between C and A ring precursors, namely tris(4-methylfuran-3-yl)boroxine (**124**) and functionalized Hagemann's ester **89**. Compound **124** was prepared from the methodology developed in our own laboratory while compound **89** was generated in two steps from a Hageman's ester derivative **102**. Suzuki cross-coupling connected two rings and yielded **125**. The bromo group was removed by acid hydrolysis of ketal **125** and Reformatsky reaction of the resulting α-bromoketone **126** to afford **127**. After reduction of **127** to alcohol **128**, Friedel-Crafts acylation of **128** led to the formation of B ring and yielded a pair of diastereomers **129** and **130**. Dess-Martin periodinane oxidation converted diastereomers **129** and **130** into **131**. Hydrogenation of the α,β-unsaturated ketone **131** furnished **132**, which exhibited *cis*-configuration between the proton at C-10 and the methyl substituent at C-5 by ^{1}H-^{1}H NOESY NMR spectroscopic analysis. Removal of the carbonyl on ring B of **132** and protection of the carbonyl on A ring with ketal, and Barton-McCombie radical deoxygenation procedure provided **136**. Acid deprotection of the ketal substituent in **136** furnished the key intermediate **137**. The key intermediate **137** may

eventually lead to tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) after several functional group transformations.

摘要

Tubipofuran (**20**) 和 15-acetoxytubipofuran(**21**) 於 1986 年從日本多莖物 *Tubipora musica* linnaeus 中分離得到。它們顯示出毒魚性和細胞毒性。我們實驗室設計了一條 C 環 + A 環 → AC 環 → ABC 環的合成路線並利用它成功合成了 3, 4–二取代呋喃和前體 **114** 和 **115**，這兩條途徑將擴展用於合成 tubipofuran (**20**) 和 15-acetoxytubipofuran (**21**) 。

本論文報道利用 C 環 + A 環 → AC 環 → ABC 環合成關鍵中間體 **137**。起初的步驟包括在 C 環和 A 環前體化合物 tris(4-methylfuran-3-yl)boroxine (**124**) 和功能化的 Hagemann's 酯 **89** 之間形成一個碳–碳鍵。化合物 **124** 利用本實驗室已有的方法製備，化合物 **89** 以 Hagemann's 酯衍生物 **102** 經兩步反應製得。Suzuki 交叉偶聯條件下連接兩個環得 **125**。酮縮醇化合物 **125** 酸解除掉保護基，生成 α-溴酮 **126** 經 Reformatsky 反應合成去溴化合物 **127**。還原 **127** 得醇 **128**。**128** 經 Friedel-Crafts 酰化反應環合形成 B 環，製得一對非對映異構體 **129** 和 **130**。非對映異構體 **129** 和 **130** 經 Dess-Martin periodinane 氧化轉化成 **131**。氧化 α,β-不飽和酮 **131** 製得 **132**，^{1}H-^{1}H NOESY NMR 光譜分析証實 **132** 的 C-10 的氫和 C-5 的甲基具有順式構型。以酮縮醇保護 A 環的羰基後除掉 **132** B 環的羰基，Barton-McCombie 脫氧製得 **136**。以酸脫掉 **136** 的酮縮醇保護製得關鍵中間體 **137**。關鍵中間體 **137** 再經幾個功能基的轉化可能最終合成 tubipofuran (**20**) 和 15-acetoxytubipofuran (**21**) 。

ABBREVIATIONS

[α]	specific rotation
δ	chemical shift in parts per million downfield from tetramethylsilane (spectral)
Ac	acetyl
AcOH	acetic acid
AIBN	α-azo-iso-butyronitrite
Anal.	analysis
Aq	aqueous
Ar	aryl
b.p.	boiling point
brs	broad singlet (spectral)
Bu	butyl
Bz	benzoyl
°C	Degrees Celsius
ca.	approximately
calcd	calculated
cat.	catalytic
conc.	concentrated
d	doublet (spectral)
DBU	1,8-diazabicyclo[5,4,0]undec-7-ene
DMI	1,3-dimethyl-2-imidazolidinone
DMSO	dimethyl sulfoxide
EI	electron impact
Et	ethyl
Et_2O	diethyl ether
EtOAc	ethyl acetate
equiv.	equivalent(s)
FAB	fast atom bombardment
FT	Fourier transform
g	gram(s)
HMPA	hexamethylphosphoric triamide
hr	hour(s)
HRMS	high-resolution mass spectrum
Hz	hertz
i-	*iso-*
IR	infrared
J	coupling constant
LAH	lithium aluminum hydride
LDA	lithium diisopropylamide
lit.	literature
m	multiplet (spectral)
M	mole per liter
Me	methyl
MeCN	acetonitrile

min	minute(s)
mL	milliliter(s)
mmHg	mm of mercury
mol	mole(s)
m.p.	melting point
MS	mass spectrometry
m/z	mass to charge ratio
n-BuLi	*n*-butyllithium
NMR	nuclear magnetic resonance
Ph	phenyl
ppm	parts per million
q	quartet (spectral)
R	alkyl etc.
r.t.	room temperature
s	singlet (spectral)
t	triplet (spectral)
THF	tetrahydrofuran
TLC	thin layer chromatography
TMS	trimethylsilyl, tetramethylsilane
p-TsOH	*p*-toluenesulfonic acid

CHAPTER 1 INTRODUCTION

1.1 General Background

1.1.1 Characteristics of sesquiterpenoid furanoeudesmanes

Furanoeudesmanes are members of the eudesmane or selinane family with furan nucleus. They are rich in higher plants, marine organisms and different natural sources.[1-2] The treasure of this class of compounds lies in their wide range of biological activities with potential pharmaceutical implications, such as antifeedant,[3-4] antispasmodic,[5] antitumor,[6-8] bactericidal agents,[8,10] cell-division inhibitor,[9] cytotoxic agents,[8,11] fungistatic,[10] ichtyotoxicity,[4,11] ixodicidic,[12] and predator deterrent.[13]

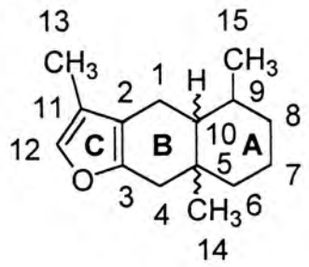

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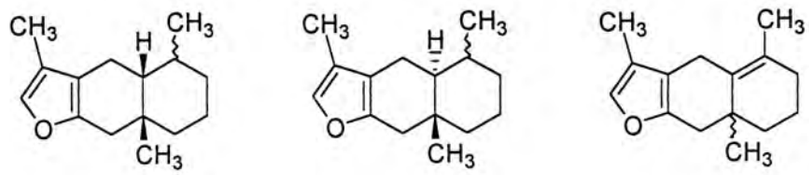
Figure 1. The primary skeleton of sesquiterpenoid furanoeudesmane.

The primary skeleton of sesquiterpenoid furanoeudesmane (**1**) is shown in Figure 1. The stereochemistry between C-5 and C-10 carbons occurs naturally in three different configuration *viz.* *cis*-(**2**), *trans*-(**3**), and C9-C10 unsaturated (**4**) (Figure 2). Different substituents and unsaturations within the molecule form different types of sesquiterpenod furanoeudesmanes.



2 3 4

Figure 2. *cis*, *trans*, and C9-C10 Unsaturated configurations of sesquiterpenoid furanoeudesmane primary skeleton.

1.1.2 Examples of *trans*-fused natural sesquiterpenoid furanoeudesmanes

There are many examples of the *trans*-configuration between C-5 and C-10 in sesquiterpenoid furanoeudesmanes (Figure 3). Furanoeudesman-1,3-diene (**5**) was obtained from the essential oil of *Commiphora molmol*.[14] Curcolonol (**6**) was found in the species of *Curcuma zedoariz*.[26] The fruits of *Smyrnium galaticum* provided 1β-acetoxyeudesma-3,7,11-triene (**7**) which is an acetoxyfuranoeudesmane.[15] On the other hand, *Smyrnium olusatrum* fruit gave furano-4(15)-eudesmen-1-one (**8**),[16] and naphtho[2,3-*b*]furan-8-ol (**9**) which is also an acetoxyfuranoeudesmane.[16-17] Shizukafuranol (**10**) was isolated from chloranthaceae in the plant of *chloranthus japonicus*.[18-19] Atractylon (**11**), 3β-acetoxyatractylon (**12**) and 3β-hydroxyatractylon (**13**) were extracted from the rhizome of *A.lancea*, *Atractylodes japonica* KOIDZUNI and its related plants.[20] *Lindera strychnifolia* and the essential oil of *Commiphora myrrh* gave lindestrene (**14**), lindenene (**15**), lindenenyl acetate (**16**), and lindenenol (**17**).[21-23] Finally, liverwort *Lophocolea heterophylla* led to the isolation of furanoeudesma-4(15),7,11-trien-5α-ol (**18**).[24]

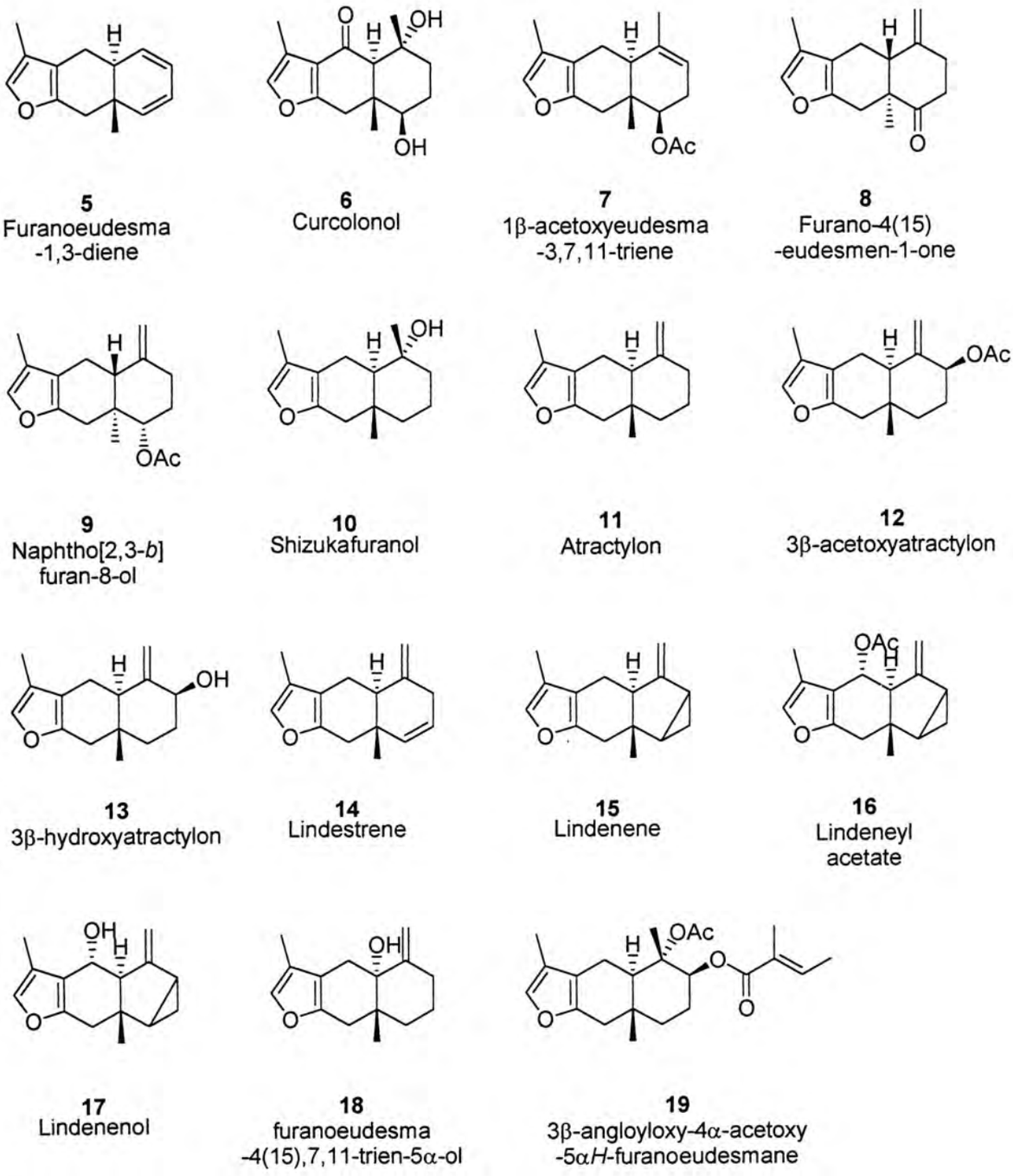


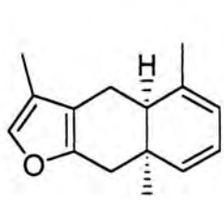
Figure 3. Some examples of the *trans*-configuration sesquiterpenoid furanoeudesmanes. Furanoeudesma-1,3-diene, curcolonol, 1β-acetoxyeudesma-3,7,11-triene, furano-4(15)-eudesmen-1-one, naphtho[2,3-*b*]furan-8-ol, shizukafuranol, atractylon, 3β-acetoxyatractylon, 3β-hydroxyatractylon, lindestrene, lindenene, lindeneyl acetate, lindenenol, furanoeudesma-4(15),7,11-trien-5α-ol, 3β-angloyloxy-4α-acetoxy-5α*H*-furanoeudesmane.

1.1.3 Examples of *cis*-fused natural sesquiterpenoid furanoeudesmanes

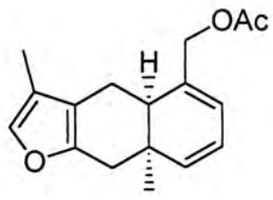
1.1.3.1 Tubipofuran and 15-acetoxytubipofuran

The *cis*-configuration sesquiterpenoid furanoeudesmanes were mainly isolated from marine sources. Tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) (Figure 4) are

the first examples of bioactive sesquiterpenoid furanoeudesmanes having a *cis*-fused A/B ring with a conjugated 1,3-diene system.



(–)-**20**
ent-Tubipofuran



(–)-**21**
ent-15-Acetoxytubipofuran

Figure 4. Two *cis*-configuration sesquiterpenoid furanoeudesmane - tubipofuran and 15-acetoxytubipofuran.

Tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) exhibit ichtyotoxicity towards a killifish *Orizias latipes*. Moreover, 15-acetoxytubipofuran (**21**) also exhibits cytotoxicity against B-16 melanoma cell *in vitro*. These compounds were obtained from Japanese stolonifer *Tubipora musica* linnaeus at the coral reef of Ishigaki Island in Okinawa, Japan in 1986.[11]

Japanese stolonifer *Tubipora musica* linnaeus suspension was extracted with ethyl acetate. Column chromatography on silica gel with hexane/ethyl acetate (30:1) gave tubipofuran (**20**) and 15-acetoxytubipofuran (**21**).

The molecular weight of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) were firstly confirmed by mass spectra in the value of 214 $[M]^+$ and 272 $[M]^+$, respectively. On the other hand, UV spectra of **20** and **21** indicate the presence of a conjugated diene system, and a 2,3,4-trisubstituted furan moiety with values at 263 nm (ε 3900), 216 nm (ε 5400) and 262 nm (ε 4300), 215 nm (ε 5500), respectively. Table 1 shows all the ^{1}H NMR and ^{13}C NMR data of **20** and **21**. Tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) showed characteristic peaks of 2,3,4-trisubstituted furan

moiety at δ 7.00 (1H, q, J = 1.1 Hz) and δ 7.00 (1H, sextet, J = 1.1 Hz), respectively. Monosubstituted homoannular diene systems in **20** and **21** were confirmed by the proton signals at δ 5.42 (1H, dd, J = 0.9, 9.5 Hz), 5.61 (1H, brd, J = 5.2 Hz), 5.81 (1H, dd, J = 5.2, 9.5 Hz) and 5.58 (1H, brd, J = 8.6), 5.85 – 5.90 (2H, m), respectively. The ^{1}H NMR and ^{13}C NMR spectra of **20** showed the olefinic methyl signal at

Table 1 ^{1}H NMR and ^{13}C NMR data of tubipofuran and 15-acetoxytubipofuran

	Tubipofuran (**20**)	15-Acetoxytubipofuran (**21**)
^{1}H NMR Data (δ ppm)	1.13 (3H, s), 1.86 (3H, brs), 1.90 (3H, d, J = 1.2 Hz), 2.01 (1H, dd, J = 5.8, 8.6 Hz), 2.19 (1H, dddd, J = 2.0, 2.9, 8.6, 15.9 Hz), 2.44 (1H, brd, J = 16.5 Hz), 2.53 (1H, tdd, J = 1.2, 5.8, 15.9 Hz), 2.63 (1H, brd, J = 16.5 Hz), 5.42 (1H, dd, J = 0.9, 9.5 Hz), 5.61 (1H, brd, J = 5.2 Hz), 5.81 (1H, dd, J = 5.2, 9.5 Hz), 7.00 (1H, q, J = 1.1 Hz).	1.15 (3H, s), 1.89 (3H, d, J = 1.3 Hz), 2.08 (3H, s), 2.14 – 2.24 (2H, m), 2.51 (1H, dd, J = 2.7, 16.6 Hz), 2.56 (1H, dd, J = 3.4, 13.4 Hz), 2.65 (1H, brd, J = 16.6 Hz), 4.63 (1H, brd, J = 13.0 Hz), 4.70 (1H, dd, J = 1.2. 13.0 Hz), 5.58 (1H, brd, J = 8.6 Hz), 5.85 – 5.90 (2H, m), 7.00 (1H, sextet, J = 1.1 Hz).
^{13}C NMR Data (δ ppm)	8.1, 22.3, 23.1, 26.0, 35.0, 35.7, 44.1, 117.8, 118.5, 118.6, 124.0, 134.7, 136.4, 140.7, 149.6.	8.0, 20.8, 23.7, 25.8, 35.2, 35.9, 40.4, 66.4, 118.96, 119.0, 121.1, 123.3, 136.6, 137.9, 138.3, 149.5, 170.7.

δ 1.86 (3H, brs) and δ 23.1, respectively. On the other hand, the ^{1}H NMR and ^{13}C NMR spectra of **21** gave the CH_2OCOCH_3 signal at δ 2.08 (3H, s), 4.63 (1H, brd, J = 13.0 Hz), 4.70 (1H, dd, J = 1.2, 13.0 Hz), and δ 66.4, 170.7, respectively. The $^{1}H - ^{1}H$ long-range correlation 2-D NMR spectra provided a W-shape long-range coupling between H-6 (δ 5.58, brd) and H-10 (δ 2.16, m) to show the *cis*-stereochemistry. Furthermore, the absolute configuration was deduced from CD spectra by a positive Cotton effect due to the helical diene system at 263 nm (Δε + 0.56) for tubipofuran (**20**) and 270 nm (Δε + 3.0) for 15-acetoxytubipofuran (**21**).

1.1.4 Examples of C9-C10 unsaturated natural sesquiterpenoid furanoeudesmanes

Examples of C9-C10 unsaturated natural sesquiterpenoid furanoeudesmanes are shown in Figure 5. Curcolone (**22**) was isolated from the rhizome of zedoary, *Curcuma zedoaria* Roscoe (Zingiberaceae) by Takemoto and co-workers in 1967.[25-26] 4-Furanoeudesmen-6-one (**23**) was obtained from the bark of *Ocotea pulchella* Nees et Mart. Ex Nees (Lauraceae) in the region of Torres, Rio Grande do Sul, Brazil by Pedralli in 1993.[27] Fenical and co-workers reported the isolation of secondary metabolites of piccolamine (**24**), piccolamine (**25**), and piccolamine *N*-oxide (**26**) from Senegalese Gorgonian *Leptogorgia piccola* in 1991.[10,28] Furthermore, furanoeudesma-1,4-diene-6-one (**27**) was found after an investigation of the essential oil of myrrh – the resin of *Commiphora molmol* Engler by Noble and co-workers in Germany, 1982 as well as Tian and co-workers in China, 1995.[14,29]

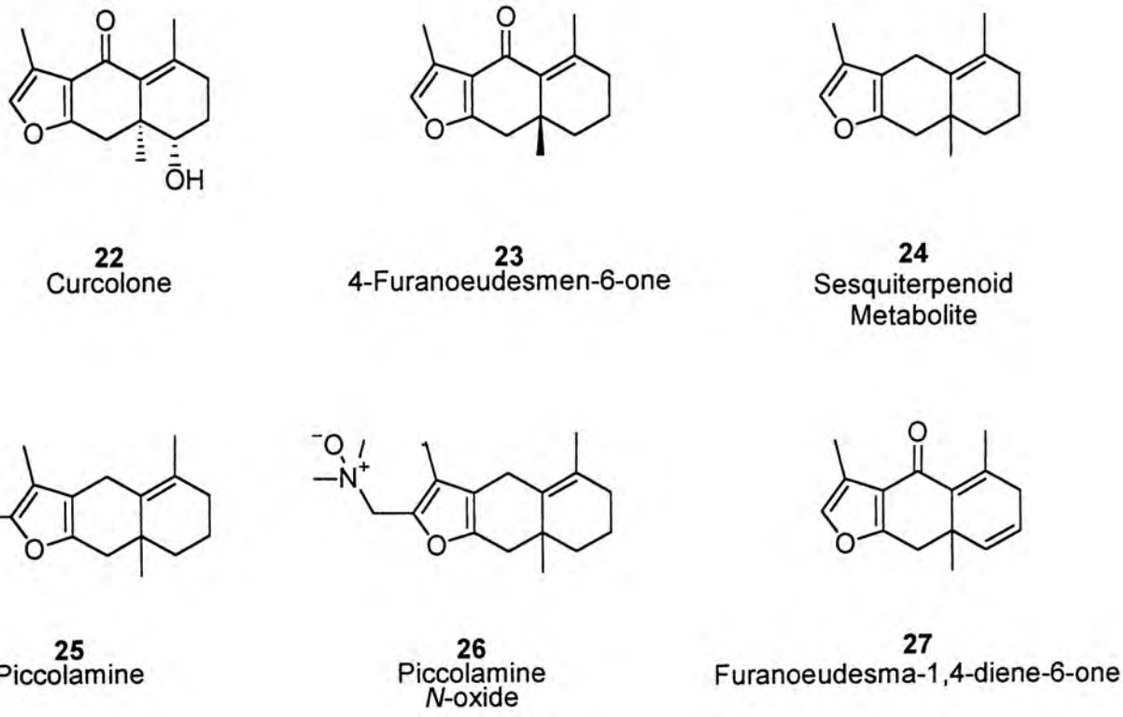
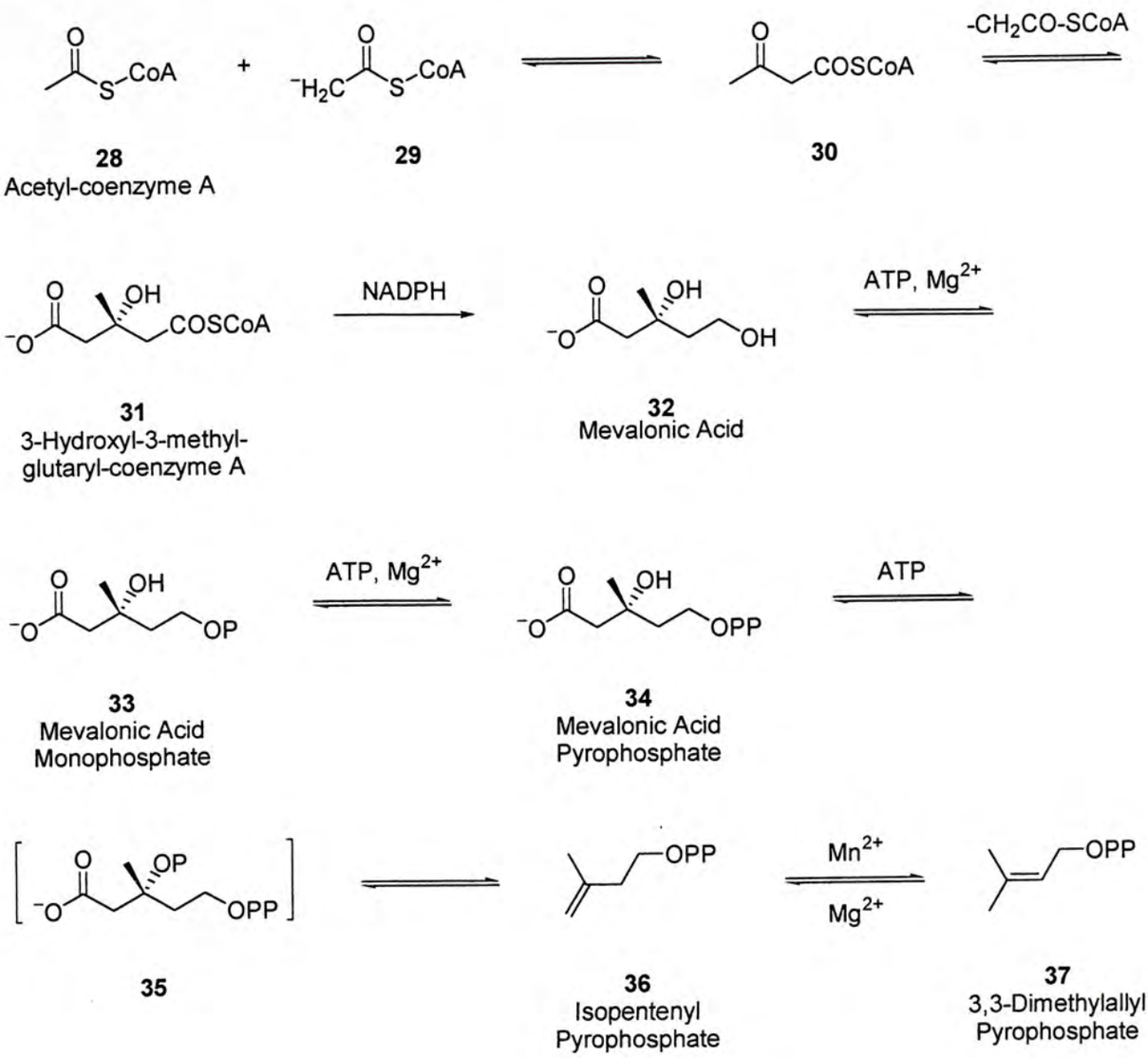


Figure 5. Some examples of the C9-C10 unsaturated sesquiterpenoid furanoeudesmanes. Curcolone, 4-furanoeudesmen-6-one, sesquiterpenoid metabolite, piccolamine, piccolamine *N*-oxide, furanoeudesma-1,4-diene-6-one.

1.2 Biosynthesis of Sesquiterpenoid Furanoeudesmanes

Detailed enzymatic studies on biosyntheses of sesquiterpenoid furanoeudesmanes have been done.[30-33] As a first step, the biological pathway starts from the formation of isopentenyl pyrophosphate (**36**) (Scheme 1). Three isopentenyl pyrophosphate (**36**) are joined to form the parent of sesquiterpenoids — 2*E*,6*E*-farnesyl pyrophosphate (**38**). Seven modes of cyclization give seven types of major cyclic sesquiterpenoids **41** (Figure 6). Only the last mode of cyclization confers the skeleton of eudesmane (**45**) (Figure 7). The biosynthetic pathway of furano group, however, is still unestablished.



Scheme 1. Formation of isopentenyl pyrophosphate unit. (OP = Phosphate, OPP = Pyrophosphate, CoA-SH = Coenzyme A)

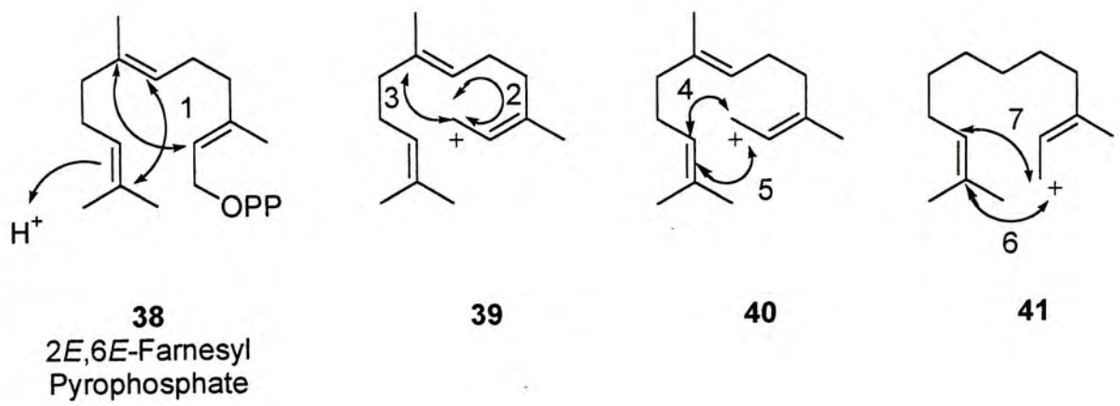


Figure 6. Seven modes of cyclization which lead to major cyclic sesquiterpenoids. (OPP = Pyrophosphate)

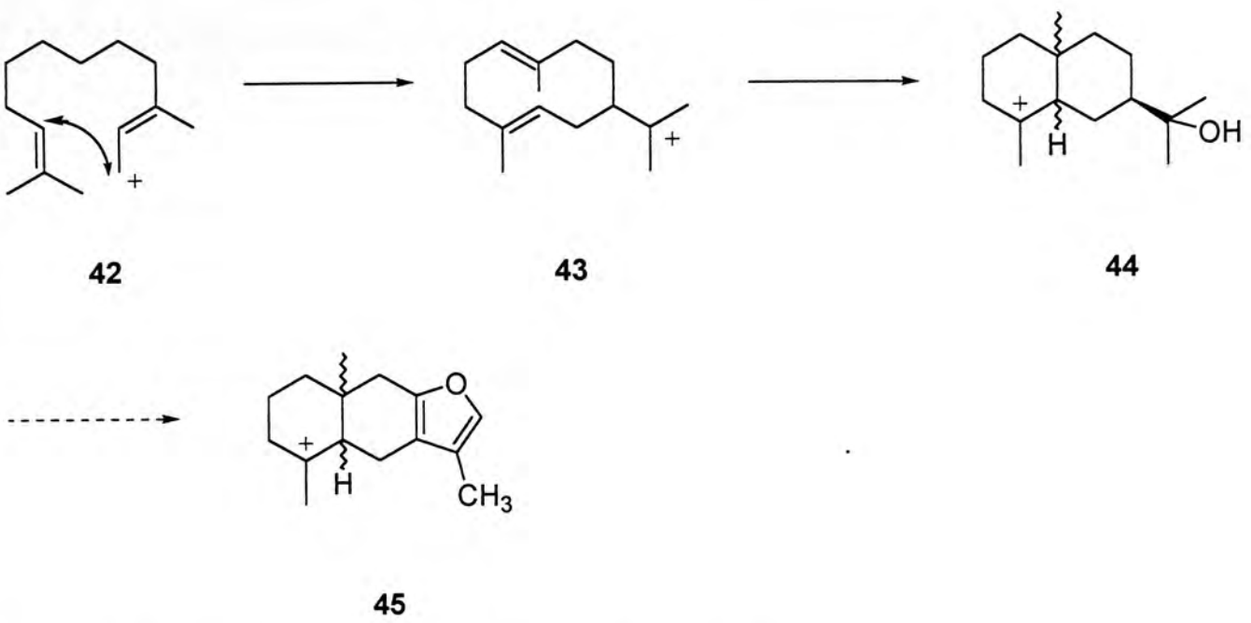


Figure 7. Formation of furanoeudesmane skeleton.

1.3 Synthesis of Sesquiterpenoid Furanoeudesmanes

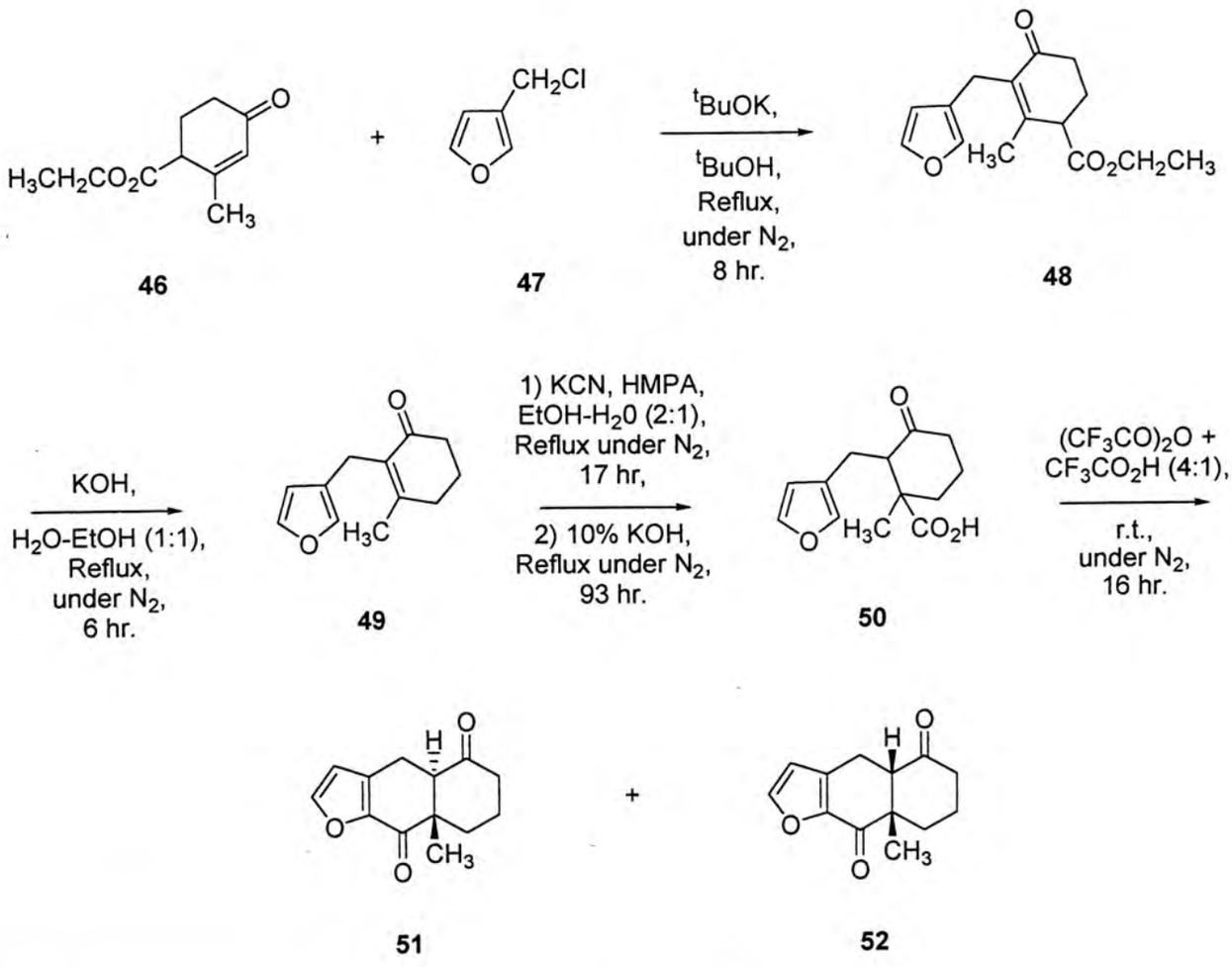
1.3.1 Synthetic examples of *trans*-fused sesquiterpenoid furanoeudesmanes

Sesquiterpenoid furanoeudesmanes could be chemically synthesized. In the case of *trans*-configuration between C-5 and C-10 in sesquiterpenoid furanoeudesmanes, Nagasaki and co-workers accomplished the first total synthesis of atractylon (**11**) starting from methoxy tetralone in 1966.[34-35] Letendre and co-workers reported a formal synthesis of atractylon (**11**) in conjunction with Nagasaki's previous work in 1980.[36] Honan achieved the total synthesis of atractylon (**11**) starting from α-tetralone in 1985.[37-38] Nagasaki and co-workers completed the first total synthesis of lindestrene (**14**) in 1968.[39] Honan also achieved the total synthesis of lindestrene (**14**) in 1985.[37]

1.3.2 Synthetic examples of *cis*-fused sesquiterpenoid furanoeudesmanes

1.3.2.1 Linearly fused A/B *trans*- and A/B *cis*-furo[3,2-*b*] and furo[2,3-*b*] decalin derivatives

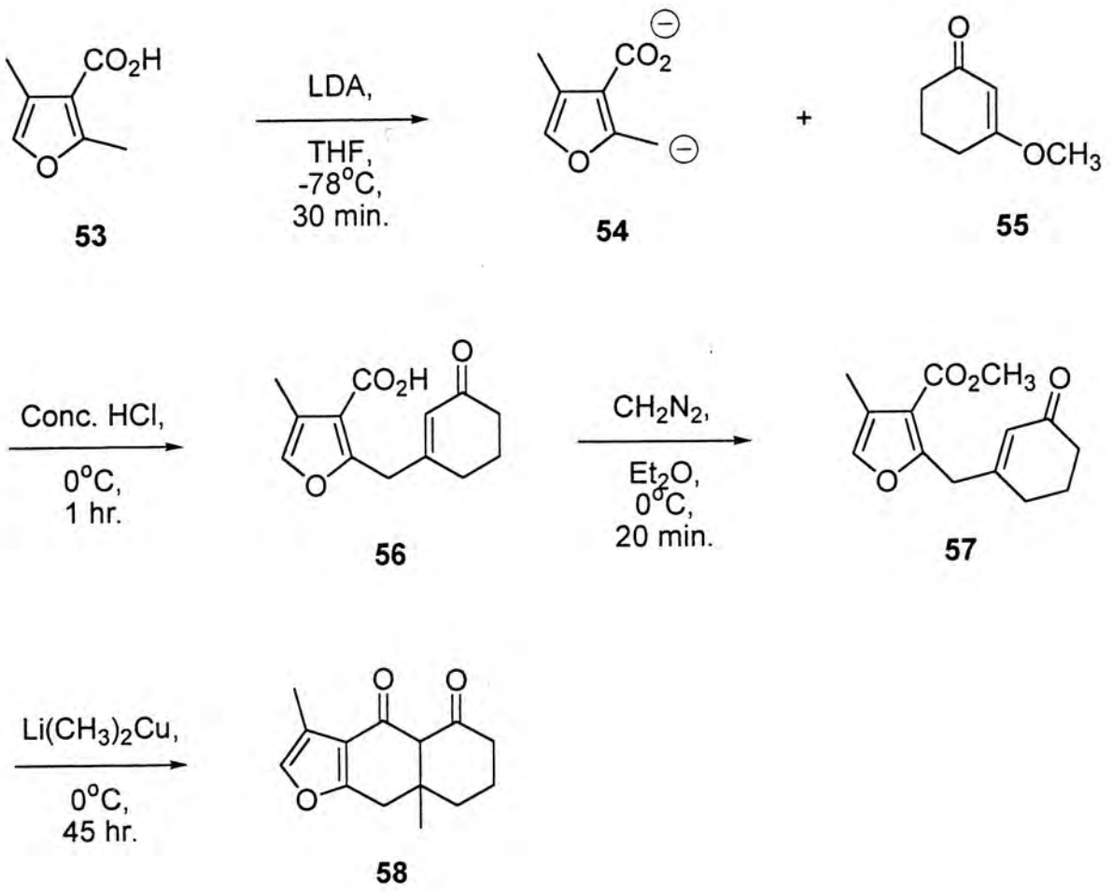
Ray and co-workers devised a route to realize linearly fused A/B *trans*- and A/B *cis*- furo[3,2-*b*] and furo[2,3-*b*] decalin derivatives with proper functionalities leading to *cis*- and *trans*-configurations of sesquiterpenoid furanoeudesmanes in 1997 (Scheme 2).[40] Hageman's ester (**46**) was alkylated with 3-furylmethyl chloride (**47**) to yield product **48**. Decarboxylation of alkylated Hageman's ester **48** gave the furylmethylcyclohexenone derivative **49**. 1,4- Addition of cyanide to the α,β-unsaturated ketone **49** and subsequent *in situ* alkaline hydrolysis resulted in the



Scheme 2 A synthetic route by Ray and co-workers for linearly fused A/B *trans*- and A/B *cis*-furo[3,2-*b*] and furo[2,3-*b*] decalin derivatives.

desired keto acid **50**, which was cyclized with a mixture of trifluoroacetic anhydride and trifluoroacetic acid to furnish a mixture of *trans*- **51** and *cis*- **52** isomers in a ratio of 1.2 to 1.

1.3.2.2 (±)-14-Norfuranoeudesmane-4,5-dione



Scheme 3 The total synthesis of (±)-14-norfuranoeudesmane-4,5-dione by Takahashi and co-workers.

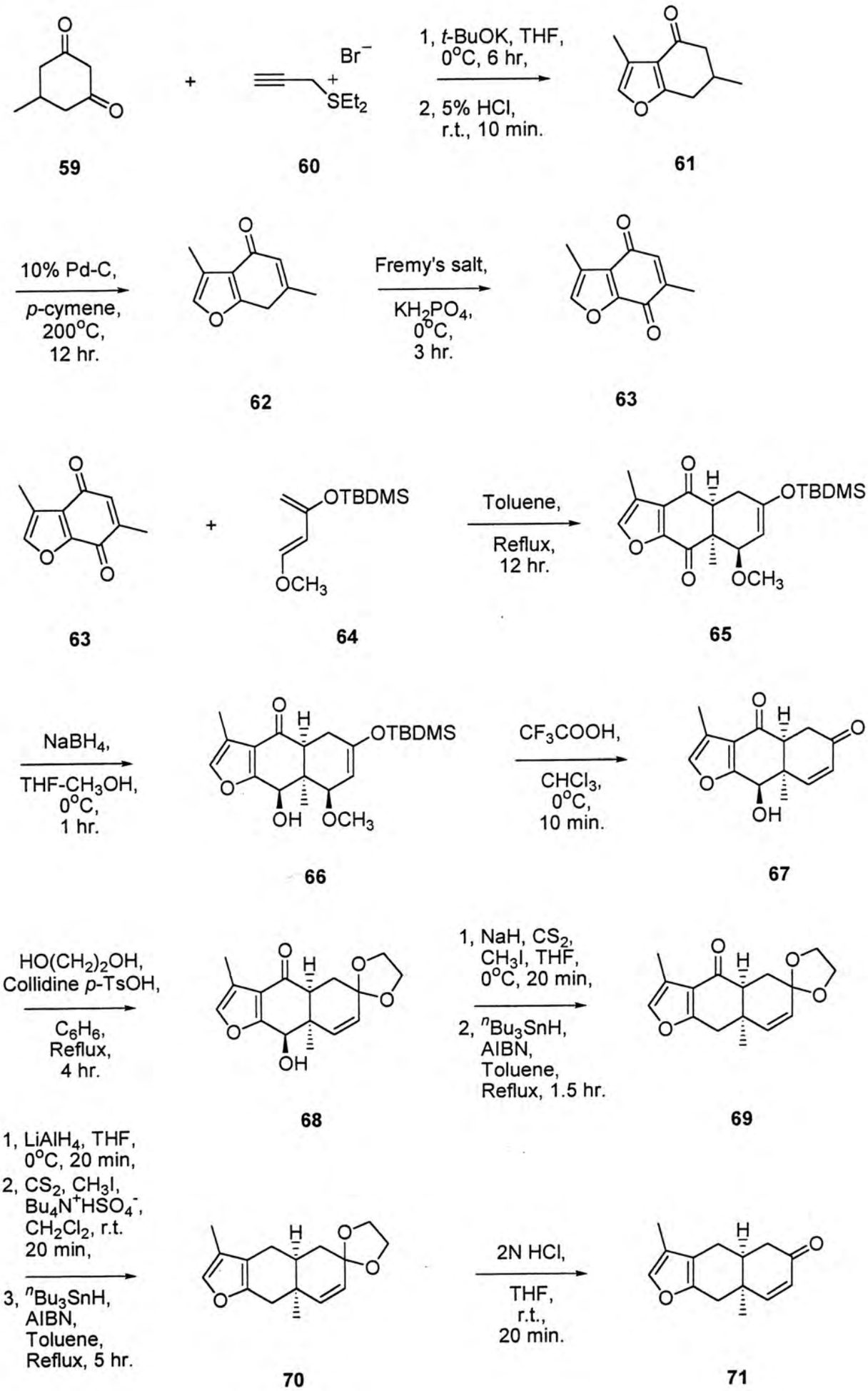
Takahashi and co-workers narrated the synthesis of (±)-14-norfuranoeudesmane-4,5-dione (**58**) in 1978 (Scheme 3).[41-42] The starting material was a dianion **54**, which was formed from 2,4-dimethyl-3-furoic acid (**53**). Compound **53** was then allowed to react with 3-methoxy-2-cyclohexen-1-one (**55**) and was subsequently acidified with hydrochloric acid to yield an acid **56**. Acid **56** was then

methylated with diazomethane to form its corresponding methyl ester **57**, which was finally transformed to the desired product, (±)-14-norfuranoeudesmane-4,5-dione (**58**), by reaction with lithium dimethylcuprate (I).

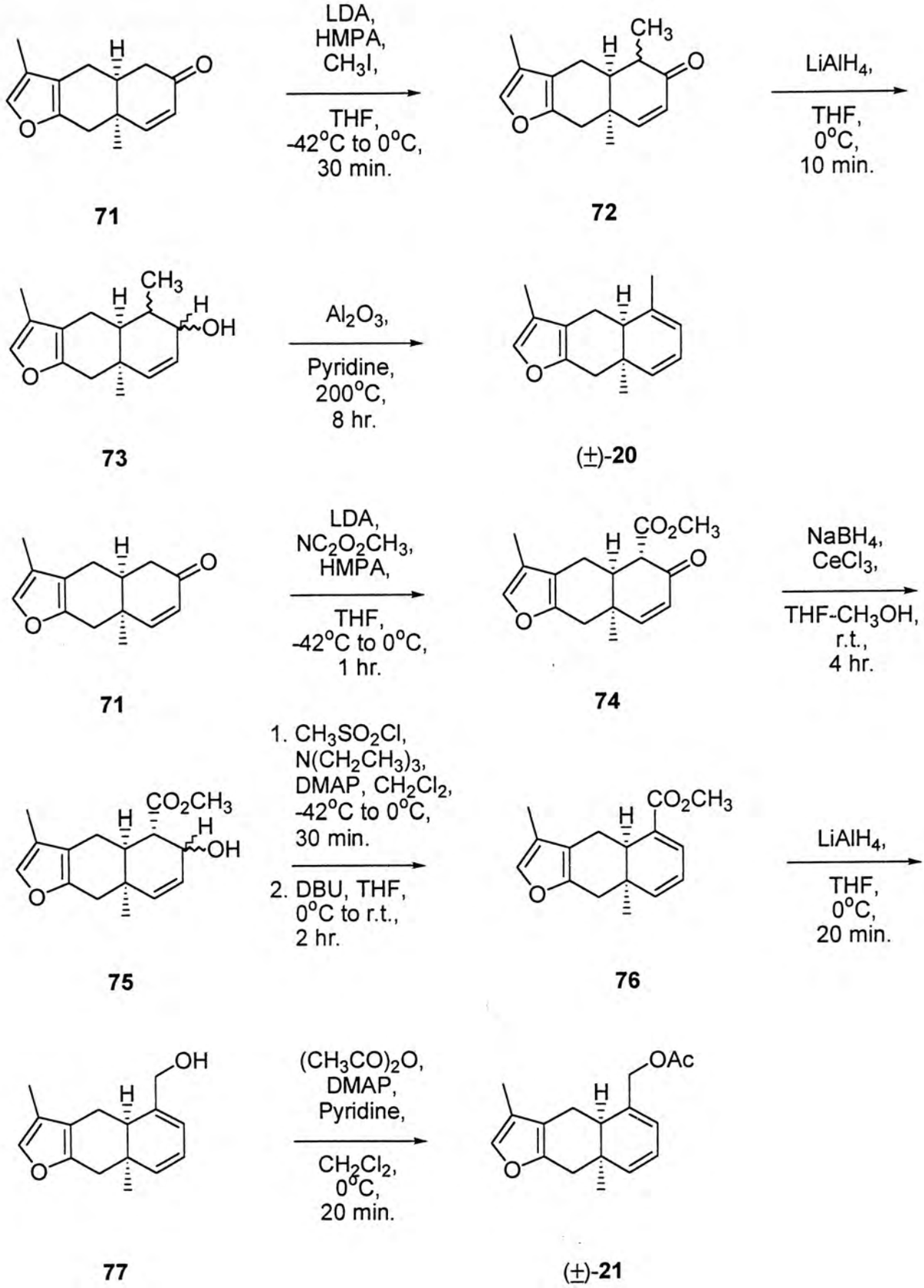
1.3.2.3 Tubipofuran and 15-acetoxytubipofuran

The first total syntheses of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) were achieved in 1994 by Kanematsu and co-workers.[43] The procedure depended on the establishment of a common intermediate **71** (Scheme 4) which led eventually to the two naturally occurring molecules (Scheme 5). 5-Methylcyclohexane-1,3-dione (**59**) reacted with a sulfur ylide to give evodone **61**, which was allowed to undergo dehydrogenation to form **62**. Benzofuranquinone **63** was obtained from the oxidation of **62**. Benzofuranoquinone **63** and Danishefsky diene[44] (**64**) were then allowed to undergo a Diels-Alder reaction, producing an *ortho-endo* adduct **65** and a *para-endo* adduct in a ratio of 11:1. The *ortho-endo* adduct **65** was reduced chemoselectively and stereoselectively with sodium borohydride to give compound **66**. Ketal **68** was obtained from compound **66** via **67** through hydrolysis, elimination and protection. Accordingly to the Barton-McCombie radical deoxygenation method,[45] ketal **68** was treated with sodium hydride, carbon disulfide, and methyl iodide to provide the corresponding xanthate. Radical deoxygenation with tributyltin hydride successfully removed the xanthate group and gave compound **69**. Reduction of another carbonyl group in the same manner yielded compound **70**. Deprotection of the ketal **70** with dilute hydrochloric acid generated the common intermediate **71**.

Methylation of the common intermediate **71** with methyl iodide and lithium diisopropyl amide afforded a mixture of epimers **72** (β-methyl:α-methyl = 11:1). Reduction of enone **72** with lithium aluminum hydride provided alcohol **73**, which



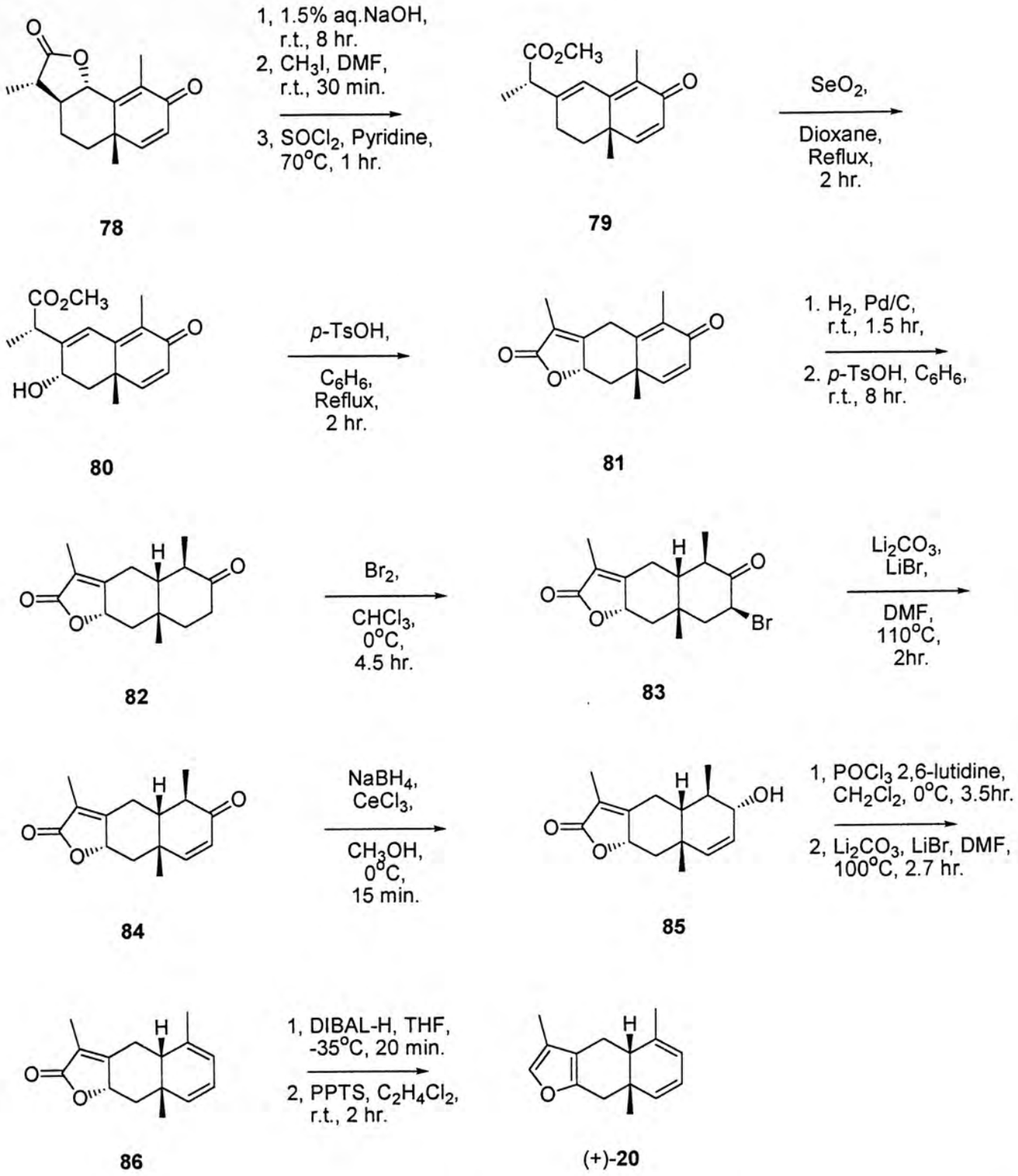
Scheme 4 The synthetic pathway of the common intermediate for the syntheses of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**).



Scheme 5 The synthetic pathway of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) from the common intermediate.

was dehydrated by using aluminum oxide in a sealed tube at 200°C to furnish the desired tubipofuran (**20**). In the case of 15-acetoxytubipofuran (**21**), acylation of the common intermediate **71** with methyl cyanoformate and lithium diisopropyl amide offered β-keto ester **74**, which was selectively reduced with sodium borohydride in the present of cerium(III) chloride, mesylated with methanesulfonyl chloride and triethylamine, and treated with 1,8-diazabicyclo[5.4.0]undec-7-ene to generate diene **76**. Finally, reduction of the diene **76** with lithium aluminum hydride, acetylation of compound **77** with acetic anhydride and pyridine finally gave 15-acetoxytubipofuran (**21**).

Pedro and co-workers constructed the enantiomerically pure form of (+)-tubipofuran (**20**) in 1996 (Scheme 6).[46] It was started from santonin (**78**), which was first converted to the hydroxy carboxylate of santonin by 1.5% sodium hydroxide solution. Methylation of the carboxyl group with methyl iodide and *in situ* dehydration of the hydroxyl group at C-6 by thionyl chloride provided the corresponding trienone **79**. Selenium dioxide oxidation of **79** offered the corresponding ketol ester **80**,[47-48] which was then transformed to butenolide **81** by treatment with *p*-toluenesulfonic acid. Hydrogenation of the butenolide **81** with 5% palladium on charcoal and *p*-toluenesulfonic acid gave the *cis*-fused ketobutenolide **82** as a major product in 75% yield.[49] In order to reintroduce a double bond between C-6 and C-9, ketobutenolide **82** was firstly converted to bromo ketone **83** by treatment with bromine. The bromo ketone **83** was dehydrobrominated by treatment with lithium carbonate and lithium bromide to provide enone **84**. On the other hand, the double bond between C-8 and C-9 was introduced in a relatively tedious procedure. Reduction of the carbonyl group with sodium borohydride in the present of cerium(III) chloride gave the corresponding alcohol **85**. The desired diene **86** was then



Scheme 6 Synthesis of the enantiomeric form of (+)-tubipofuran (**20**) by Pedro and co-workers.

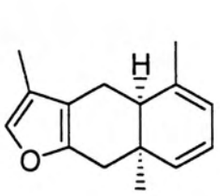
successfully obtained through the formation of two epimeric allylic chlorides by reaction with phosphorus oxychloride in the presence of 2,6-lutidine and subsequent elimination by lithium carbonate and lithium bromide. Lastly, development of the furan ring from the diene **86** was carried out by reduction with diisobutylaluminum hydride to yield two epimeric lactols, which were then dehydrated by the disodium

salt of 3-[5-(sulfophenyl)-2-pyridyl]-1,2,4-triazin-5-ylbenzenesulfonic acid. Consequently, formation of the enantiomerically pure form of (+)-tubipofuran (**20**) was achieved, which was proven to be the identical stereocongener with natural tubipofuran (**20**).

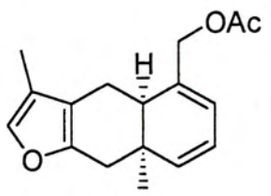
CHAPTER 2 RESULTS AND DISCUSSION

2.1 Aim of Present Work

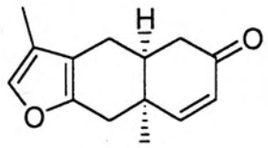
Tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) are sesquiterpenoid furanoeudesmanes having the *cis*-configuration between C-5 and C-10 carbons. Kanematsu and co-workers achieved the first total syntheses of these two compounds from a common intermediate **71** through a B ring → BC ring → ABC ring approach in 1994.[43] Recently, Yick from our laboratory successfully synthesized the raw skeleton of sesquiterpenoid furanoeudesmane **87** with C9-C10 unsaturation through a C ring + A ring → AC ring → ABC ring approach.[50] It was expected that **87** could be converted into the common intermediate **71** which eventually led to the natural products tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) after several functional group transformations. Furthermore, this approach began with an organosilicon-organoboron protocol, which was well established in our laboratory.[51-56] With these hints, it is critical to commence with the production of functionalized Hagemann's ester **89**, and tris[4-(trimethylsilyl)furan-3-yl]boroxine (**88**)[51-55] from 3,4-bis(trimethylsilyl)furan. A Suzuki cross-coupling[57-59] of C ring and A ring, with a subsequent Friedel-Crafts acylation, would lead to the formation of B ring and provide the starting material **87**. Reduction of the double bond to *cis*-configuration between C-5 and C-10 carbons, and transformation of other function groups in A, B and C rings would likely yield the common intermediate **71**, as well as achieving the formal syntheses of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**). Some details of this approach are described in the Retrosynthetic Scheme (Figure 8).



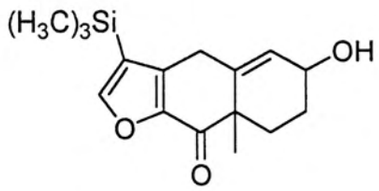
20
Tubipofuran



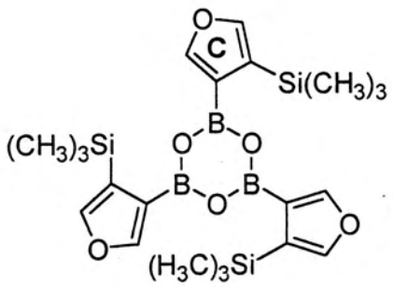
21
15-Acetoxytubipofuran



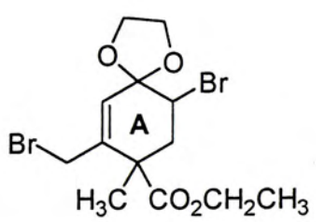
(±)-**71**



87



88



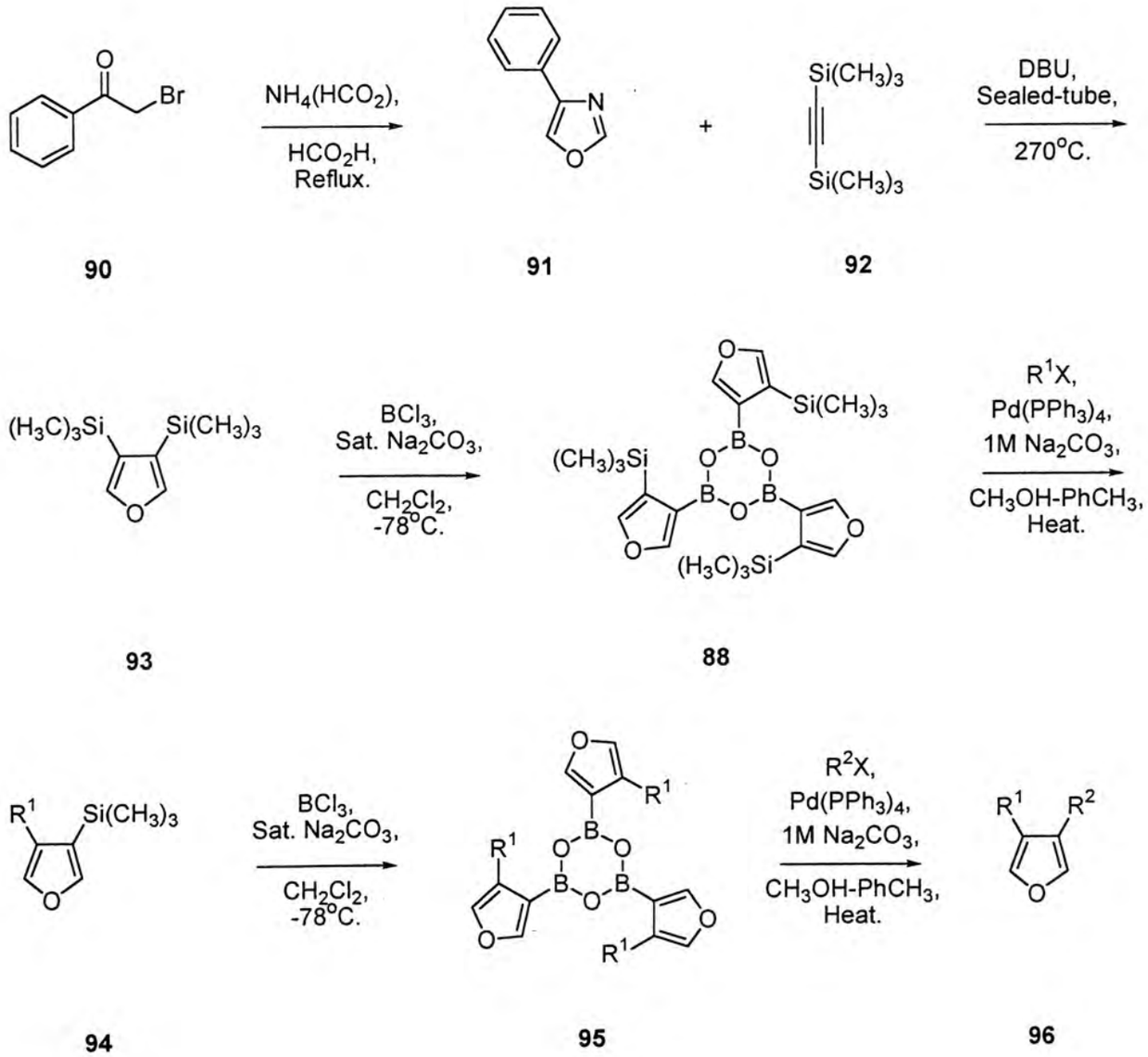
89

Figure 8. Retrosynthetic Scheme.

2.2 C ring + A ring → AC ring → ABC ring Scheme A

2.2.1 Preparation of C ring in Scheme A

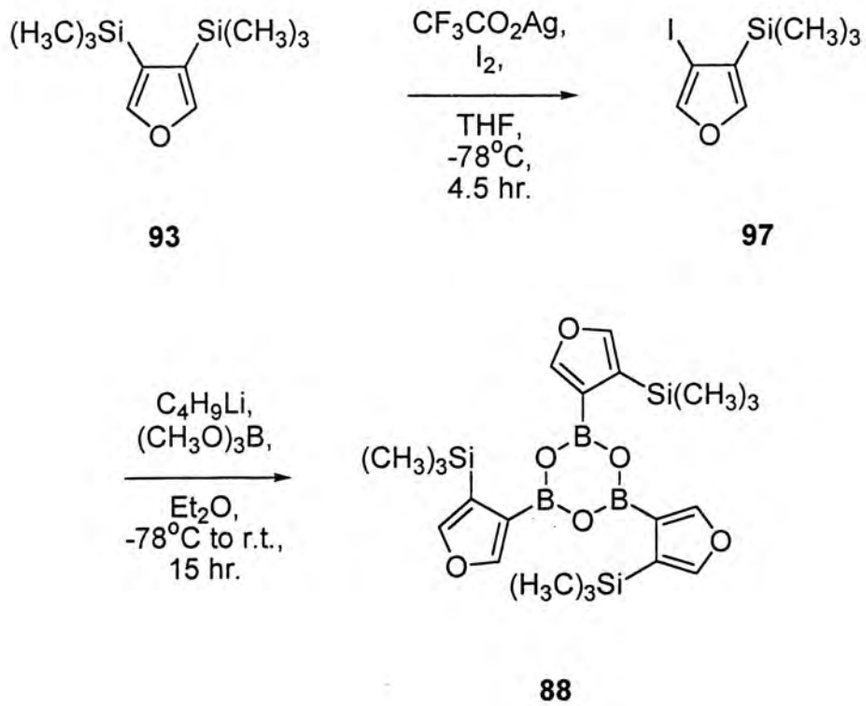
Tris[4-(trimethylsilyl)furan-3-yl]boroxine (**88**)[51-55] was the precursor of C ring in the primary skeleton of sesquiterpenoid furanoeudesmane **87**. Several papers from our laboratory exemplified the preparation of isolable boroxines and 3,4-disubstituted furans (**96**).[52-55] Thus, 4-phenyloxazole (**91**)[60,63] was synthesized from 2-bromoacetophenone (**90**).[63] The Diels-Alder reaction between 4-phenyloxazole (**91**)[60,63] and bis(trimethylsilyl)acetylene (**92**)[64-65] gave **93** which was the precursor of



Scheme 7 Synthetic pathway of 3,4 disubstituted furan.

our synthetic procedure.[52-56,60-62] 3,4-Bis(trimethylsilyl)furan (**93**) was then converted to boroxine **88**.[51-55] In addition, formations of 3,4-disubstituted furans (**96**) (R^2 = allyl, aryl and benzyl) were also achieved through the isolable boroxines **88** and **95** (Scheme 7).

In considering the reactivity and inaccessibility of boron trichloride solution, we attempted to synthesize tris[4-(trimethylsilyl)furan-3-yl]boroxine (**88**)[51-55] by another route. Thus, 3,4-bis(trimethylsilyl)furan (**93**) was converted to 4-iodo-3-(trimethylsilyl)furan (**97**) by treatment with iodine and silver trifluoroacetate.[51-52,55] Tris[4-(trimethylsilyl)furan-3-yl]boroxine (**88**)[51-55] were subsequently obtained by treatment of **97** with butyllithium followed by addition of trimethyl borate (Scheme 8). However, the yield of the reaction is low, so this route is impossible to be used as an alternative to generate tris[4-(trimethylsilyl)furan-3-yl]boroxine (**88**).[51-55]

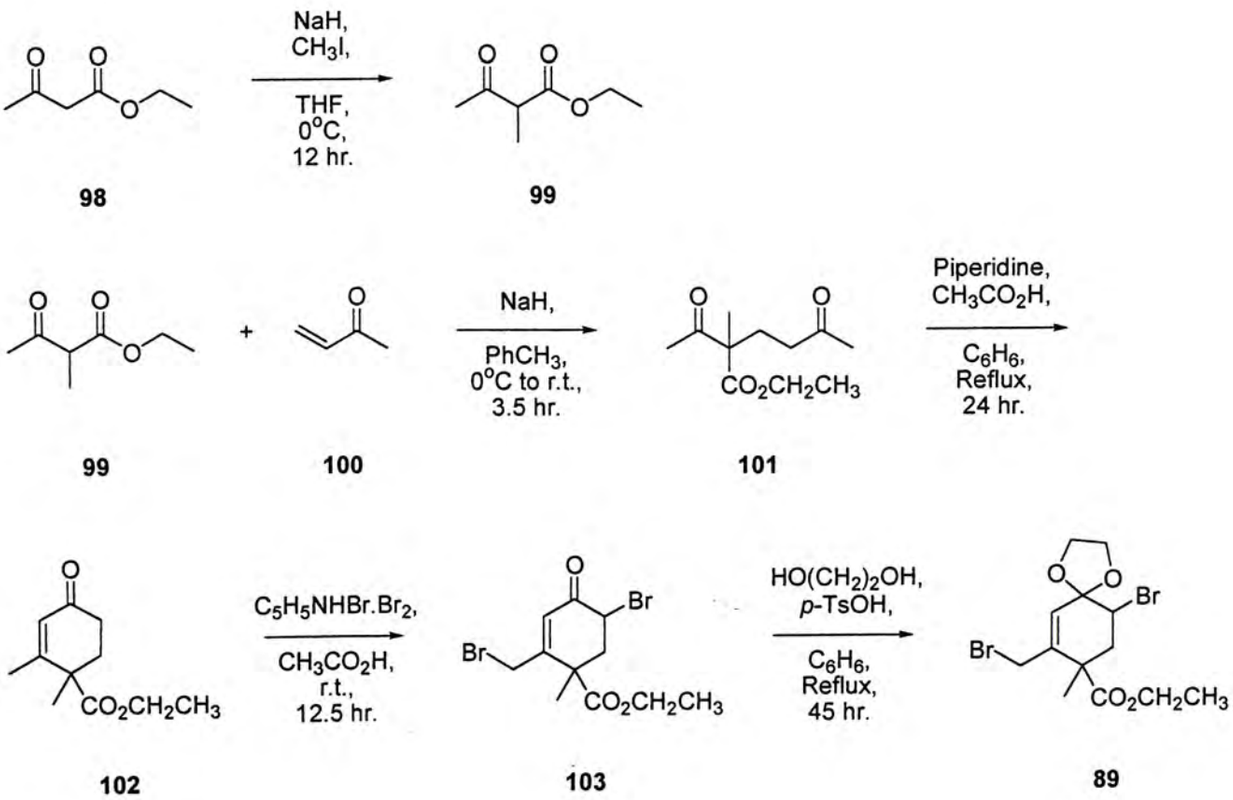


Scheme 8 Synthetic pathway of tris[4-(trimethylsilyl)furan-3-yl]boroxine.

2.2.2 Preparation of A ring in Scheme A

The precursor of A ring in the primary skeleton of sesquiterpenoid furanoeudesmane **87** was the functionalized Hagemann's ester **89** (Scheme 9).[50] Firstly, methylation of ethyl acetoacetate (**98**) with methyl iodide and sodium hydride proceeded smoothly in 0°C and afforded the desired product ethyl 2-methylacetoacetate (**99**) in over 80% yield after purification under vacuum distillation. The experiment was carried out at multi-gram scale with no difficulty.

1,4-Michael addition of the enolate of ethyl 2-methylacetoacetate (**99**) to methyl vinyl ketone (**100**) at 0°C to room temperature (25°C) offered compound **101** in 70% yield after purification under vacuum distillation.[66] This step was performed at 50-gram scale and provided the essential starting material for cyclization.



Scheme 9 Synthetic pathway of the precursor of A ring - functionalized Hagemann's ester.

Plieninger and co-workers successfully synthesized δ–keto-ester **102** from the cyclization of compound **101**.[66] During the cyclization of dioxo-ester **101**, the desired δ-keto-ester **102** and the side product β-keto-ester **104** are likely to produced in different amount (Figure 9).[67] The relative ratio of these two isomers undoubtedly depends on the reaction conditions, kinetics and equilibrium factors. Acid-catalyzed cyclization of dioxo-ester **101** would likely lead to the undesired β-keto-ester **104** as a major product. On the contrary, the usage of piperidinium acetate or pyrrolidinium acetate as catalyst would furnish the desired δ-keto-ester **102** after cyclization.[66,68] As pyrrolidinium acetate is likely to participate in the intramolecular condensation of an enamine with a carbonyl group, the subsequent elimination of water, and the hydrolysis of an intermediate iminium ion. Moreover, product equilibration does not take place in the cyclization when pyrrolidinium acetate participates.

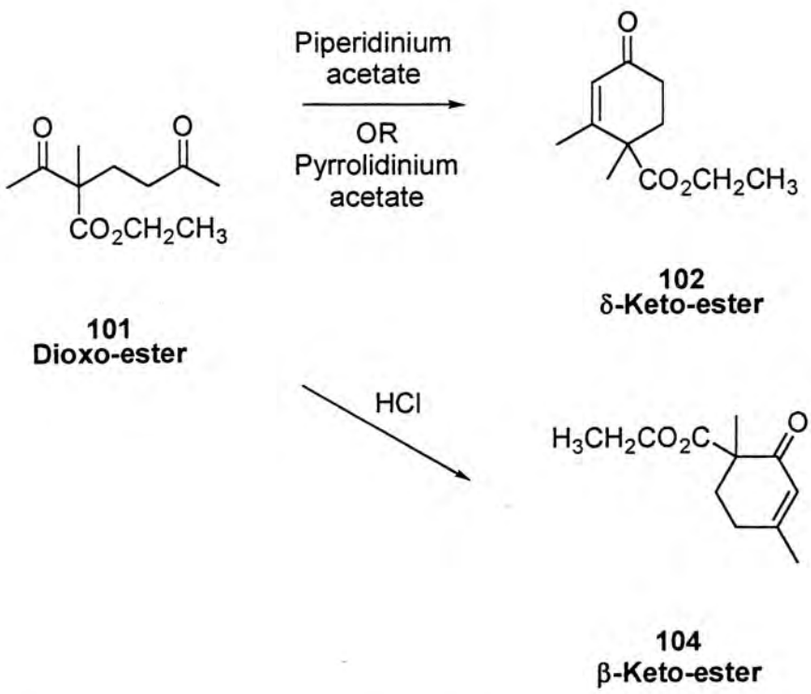


Figure 9. The desired δ-keto-ester and the side product β-keto-ester from cyclization of dioxo-ester.

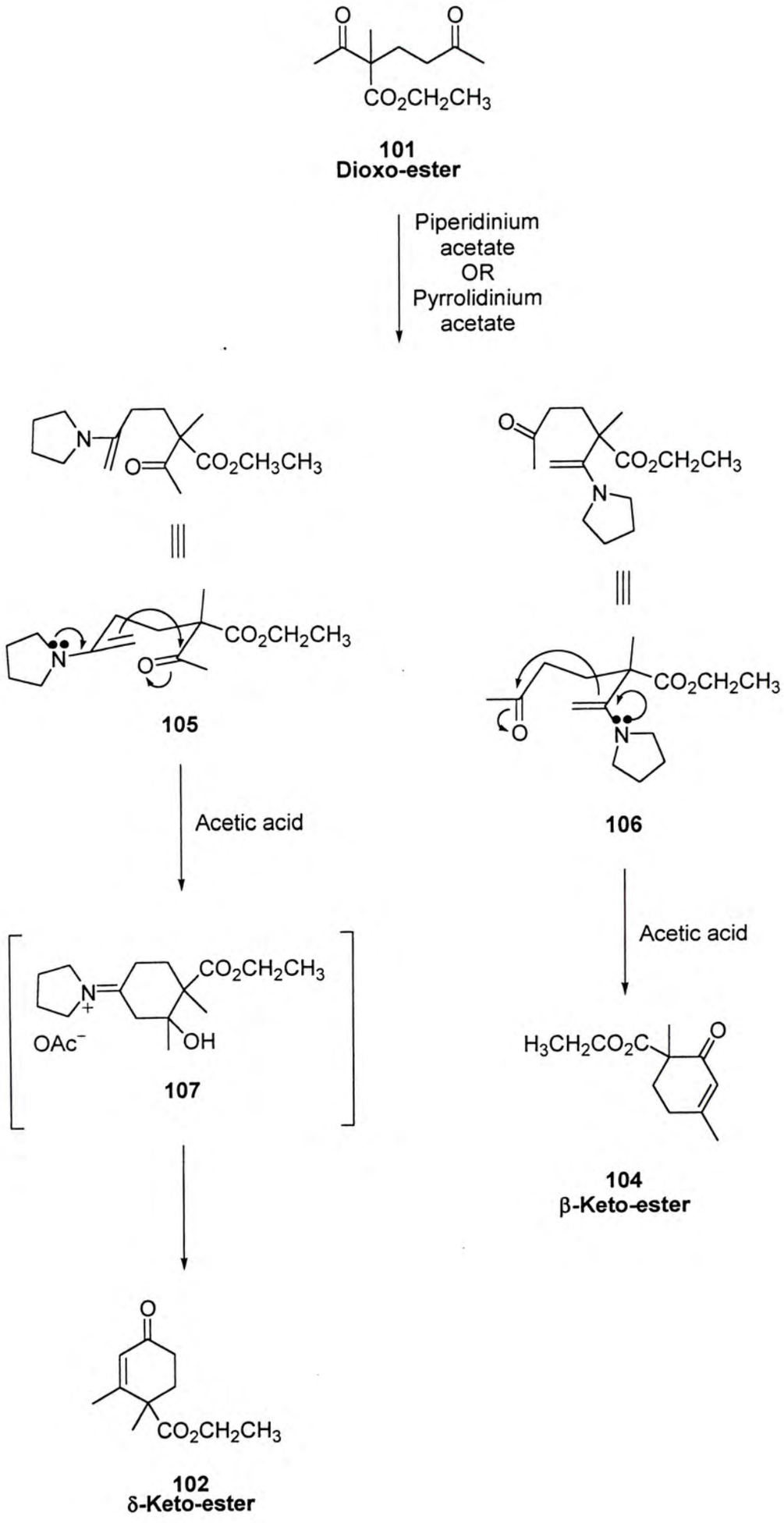
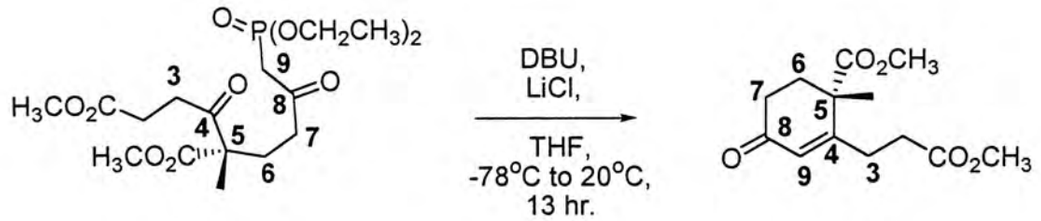


Figure 10. Several intermediates during the formation of δ-keto-ester and β-keto-ester.

Preferable formation of the desired δ-keto-ester **102** rather than the side product β-keto-ester **104** in the presence of piperidinium acetate or pyrrolidinium acetate can be rationalized by the fact that intermediate **105** would cyclize much faster than intermediate **106** due to its greater steric crowding in the transition state for cyclization. What is more, intermediate **105** shows maximum orbital overlap of the double bond π-electrons with the lone-pair electrons on nitrogen. Intermediate **107** is produced after cyclization, and is then trapped in the presence of acetic acid. Hydrolysis of the pyrrolidinium go on and dehydration gave the desired δ-keto-ester **102** (Figure 10).

In recent years, Gassama and co-workers realized an efficient way for the annulation of diketones **108** to δ-keto-ester **109** through the internal Horner-Wadsworth-Emmons condensation with the help of 1,8-diazabicyclo[5.4.0]undec-7-ene and lithium chloride (Scheme 10).[69] The efficiency of this reaction can also be shown by its 70% yield.



108 **109**

Scheme 10 Synthesis of Hagemann's ester derivative through Horner-Wadsworth-Emmons annulation.

Bromination of δ-keto-ester **102** with pyridinium bromide perbromide in acetic acid gave dibromide **103** as a diastereomeric mixture in a ratio of 2 to 1.[50,70] Bromination at C-7 is an undesirable outcome. However, several conditions were

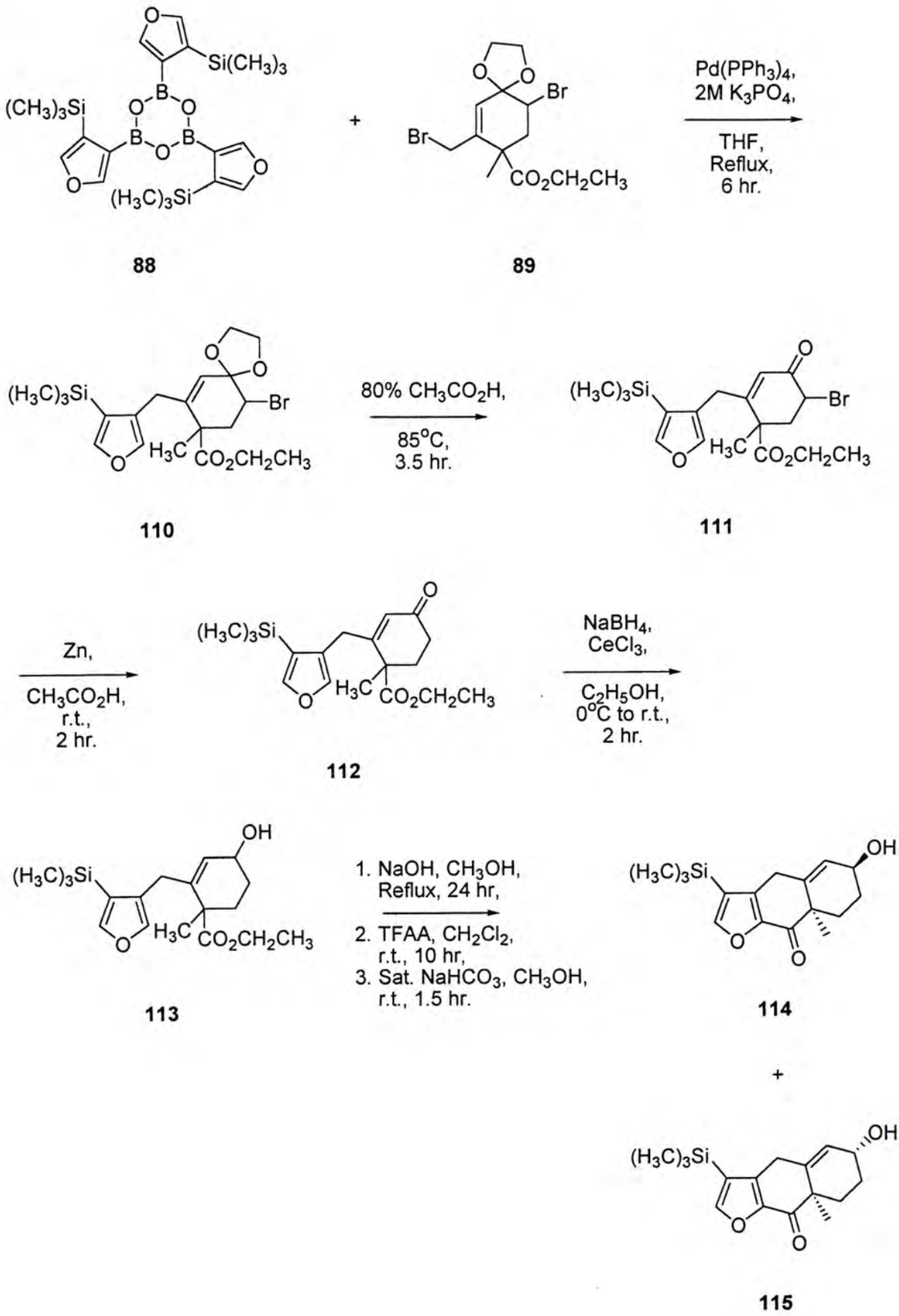
examined and led us to the conclusion that the undesirable bromination could not be avoided. Protection of enone with ethylene glycol followed by bromination of the resulting ketal was also tried, but only a messy mixture was resulted.[50]

Dibromide **103** was unstable in basic conditions, so a direct coupling with tris[4-(trimethylsilyl)furan-3-yl]boroxine (**88**)[51-55] has never been achieved.[50] As a result, protection of carbonyl group in dibromide **103** with ethylene glycol gave the functionalized Hagemann's ester **89** as the precursor of A ring. Fortunately, compound **89** could underwent Suzuki cross-coupling[57-59] efficiently.

2.2.3 Formation of B ring in Scheme A

When the precursors of A ring and C ring were realized, cyclization of B ring was then performed (Scheme 11). Suzuki cross-coupling[57-59] of tris[4-(trimethylsilyl)furan-3-yl]boroxine (**88**)[51-55] with functionalized Hagemann's ester **89** in aqueous potassium phosphate and tetrakistriphenylphosphine palladium(0) catalyst generated compound **110** in good yield. Moreover, compound **110** was produced as a diastereomeric mixture in a ratio of 1.5 to 1. Reduction of the bromide substituent in compound **110** was tried before the deprotection of ketal group, but several reaction conditions (sodium borohydride in hot dimethylsulfoxide, tributylstannyl hydride and AIBN in refluxing toluene or generation of Grignard reagent followed by hydrolysis) failed to remove the bromine.[50]

Deprotection of ketal group in compound **110** with 80% acetic acid was performed prior to the removal of the bromide substituent. Bromoenone **111** was produced as a diastereomeric mixture in a ratio of 9 to 1. Compound **111** decomposed readily, and was showed unstable under explosure to air at room temperature, or under sunlight.



Scheme 11 Synthetic pathways of connection of A ring and C ring, as well as formation of B ring.

Reformatsky reaction of **111** in the presence of zinc dust in glacial acetic acid successfully removed the undesirable bromide substituent, and provided enone **112** in 87% yield. Protection of enone **112** as ketal with ethylene glycol was tried prior to

cyclization. However, it was found that the double bond in A ring was shifted, resulting in exo configuration of the double bond, which did not lead to efficient cyclization.[50] Other types of protection were not attempted in this case because the double bond migration would undoubtedly occur.[50]

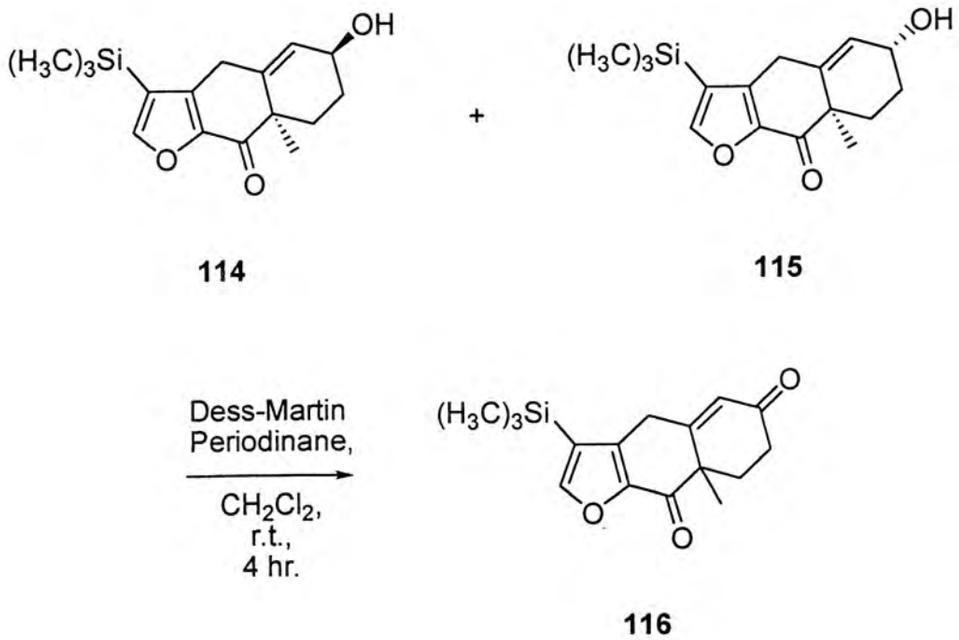
The strategy was adjusted so that reduction of the carbonyl into hydroxyl was attempted before cyclization. Thus, reduction of enone **112** proceeded smoothly with sodium borohydride, and cerium(III) chloride in ethanol, providing alcohol **113** in 86% yield as a diastereomeric mixture in a ratio of 2 to 1.

Finally, the cyclization involved three steps. Thus, base hydrolysis of the ester moiety with sodium hydroxide was followed by a Friedel-Crafts acylation, and the hydrolysis of the trifluoroacetate intermediate. In this way, a pair of diastereomers **114** and **115** were furnished.

Several experiments were attempted in the conversion of the trimethylsilyl substituent on the C ring of diastereomers **114** and **115** into a methyl substituent. Consequently, initial iodination of **114** and **115** with iodine and silver trifluoroacetate[51-52,55] followed with methyl group coupling failed. Conversion of **114** and **115** to the corresponding methyl substituted furan was also attempted to no avail by treatment with boron trichloride solution or boron tribromide, and followed by a Suzuki cross-coupling[57-59] of the corresponding boroxine or boronic acid with methyl halide. Moreover, peracid oxidation[76] of **114** and **115** was also tried in vain to generate the corresponding ketone. Subsequent nucleophilic addition of the ketone with methyllithium with dilute hydrochloric acid treatment would likely give the desired compounds.[77] Unfortunately, this procedure failed to generate the desired intermediate after several trials.

Hydrogenation was also attempted to eliminate the alkene in A ring so that an investigation of the configuration between C-5 and C-10 of the product could be carried out. In this reaction, diastereomers **114** and **115** were hydrogenated over palladium on activated carbon and resulted in four different compounds in low yield and in an inseparable manner.

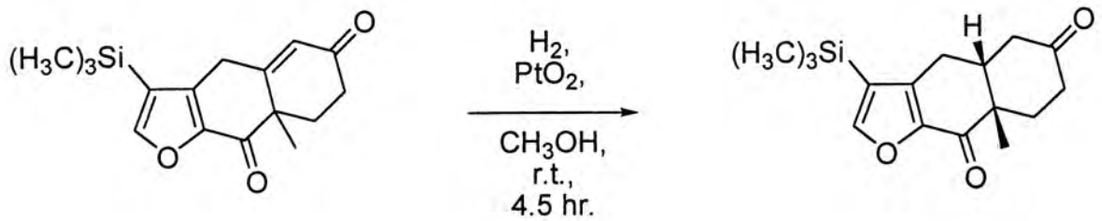
With a pair of cyclized diastereomers **114** and **115** in hand, transformations of functional groups in different orders were sought. Dess-Martin periodinane oxidation[71-73] turned the pair of diastereomers **114** and **115** into a single enone **116** (Scheme 12). Signals at δ 5.95 in the ^{1}H NMR spectrum and δ 207.1 in the ^{13}C NMR spectrum indicated the successful formation of the desired compound.[50] The highly acidic methylene protons on B ring, however, led to $\Delta^{1,10}$ isomer along with compound **116** in the ratio of 3:1 during column purification on silica gel.[50]



Scheme 12 Oxidation of compounds **114** and **115**.

A couple of trials in the conversion of the trimethylsilyl substituent into methyl substituent in C ring were also tried but no positive result was secured. Furthermore, peracid oxidation[76] of **116** was tried to generate the corresponding ketone, but again the conversion failed.

Compound **117** was furnished by hydrogenation of the α,β-unsaturated ketone **116** and its $\Delta^{1,10}$ isomer (Scheme 13). After several attempts to hydrogenate the double bond of compound **116**, hydrogenation on Adams' catalyst[74-75] in methanol was finally chosen, because it gave better yield and required shorter reaction time (Table 2). On the other hand, hydrogenation of **116** on palladium on activated carbon[43,78] in dichloromethane only resulted in lower yield. Reduction of **116** with triethylsilane mediated by copper(I) chloride in 1,3-dimethyl-2-imidazolidinone[79] led to a very unacceptable yield. Reduction of **116** with zinc chloride, triethylsilane and tetrakis(triphenylphosphine)palladium(0)[80] in chloroform failed completely.



116 (±)-**117**

Scheme 13 Hydrogenation of compound **116**.

Compound **117** was able to form colorless needle-shape crystals from hexane and ethyl acetate at -4°C, but melted and turned into colorless oil while returning to room temperature. The ^{1}H NMR spectrum of **117** indicated three singlets at δ 0.22, 1.31 and 7.46, which represented the trimethylsilyl protons, the methyl protons, and the furan α-proton, respectively. The proton at C-10 was displayed at δ 1.50, while

Table 2 Different conditions for hydrogenation of enone **116**

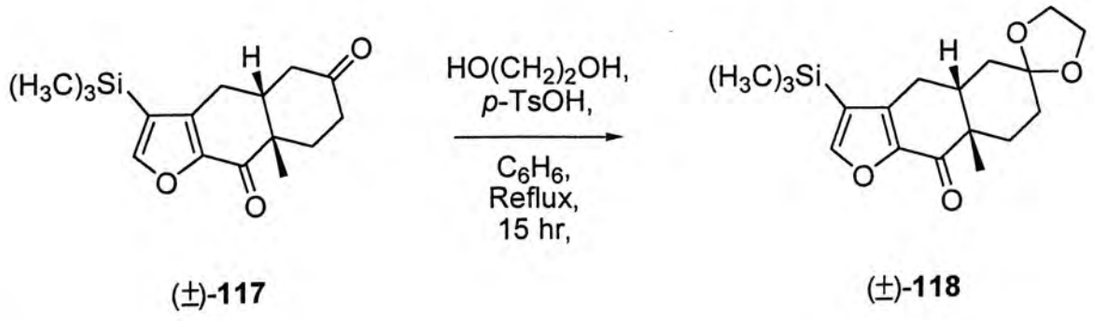
Entry	Catalyst/ Reagent	Solvent	Temperature (°C)	Time (hr)	Yield (%)
1	10% Pd/C	CH_3OH	20	18.5	12
2	10% Pd/C	CH_3OH	20	5.5	22
3	10% Pd/C	CH_2Cl_2	-78	3	No Reaction
4	10% Pd/C	CH_2Cl_2	0	5.5	53
5	10% Pd/C	CH_2Cl_2	20	4	11
6	10% Pd/C	CH_3CN	0	3	No Reaction
7	10% Pd/C	CH_3CN	20	20	8
8	PtO_2	CH_2Cl_2	-78	4	No Reaction
9	PtO_2	CH_2Cl_2	0	6	7
10	PtO_2	CH_2Cl_2	20	21	24
11	PtO_2	CH_3OH	-78	4	No Reaction
12	PtO_2	CH_3OH	0	3	11
13	PtO_2	CH_3OH	20	4.5	59
14	CuCl $(C_2H_5)_3SiH$	DMI	20	24	8
15	$ZnCl_2$ $(C_2H_5)_3SiH$ $Pd(PPh_3)_4$	$CHCl_3$	20	21	No Reaction

the protons at C-1 appeared at δ 2.63 and 3.13. A multiplet between δ 2.22 and 2.56 indicated the presence of other protons. The ^{13}C NMR spectrum showed 14 types of carbons. Two carbonyl carbons were formed at δ 188.6 and 210.3. The furan carbons appeared at δ 121.1, 139.5, 146.2 and 152.8. The trimethylsilyl carbons appeared at δ -1.0. The methyl carbon was placed at δ 23.4. The C-1, C-6, C-10, C-7, C-9 and C-5

carbons appeared at δ 27.1, 32.8, 38.6, 43.8, 44.7, and 46.7, respectively. The elemental analysis and high resolution mass spectrometry agreed with the structure. However, the configuration between C-5 and C-10 carbons was not revealed in this stage.

Several experiments were attempted in the conversion of the trimethylsilyl substituent on the C ring of compound **117** into a methyl substituent.[51-59,81] However, no positive result was secured.

Protection of the carbonyl group on A ring of compound **117** with ethylene glycol in refluxing benzene yielded a protected compound **118** with good yield of 83% (Scheme 14). Compound **118** appeared as colorless needle-shape crystals from hexane and ethyl acetate. The structure of 4,5,7,8-tetrahydro-8a-methyl-6,6-(1',3'-dioxolan-2'-yl)-3-(trimethylsilyl)naphtho[2,3-*b*]furan-9-one (**118**) was confirmed by an X-ray crystallography study (Figure 11). It is worthy to note that the *cis*-configuration between C-5 and C-10 was revealed after hydrogenation on Adams' catalyst.[74-75] The X-ray result clearly pointed out that a unit cell is composed with two enantiomers with C-5 proton and C-10 methyl substituent above and below the molecular plane in the ratio of 3 to 1. The ^{1}H NMR spectrum of **118** indicated a multiplet of 4H between δ 3.79 and 3.91 for the newly formed ketal substituent. The



(±)-**117** (±)-**118**

Scheme 14 Protection of compound **117**.

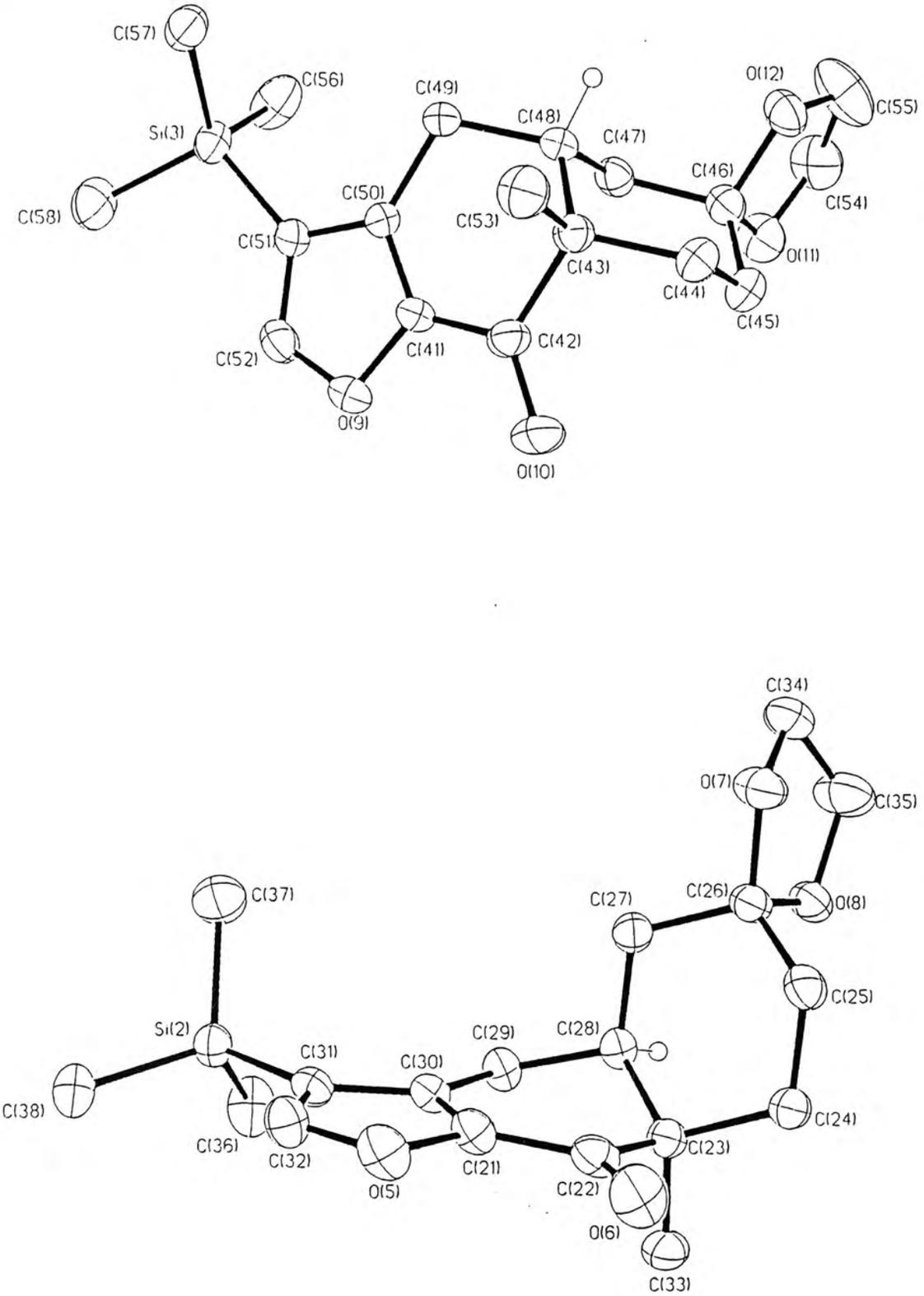
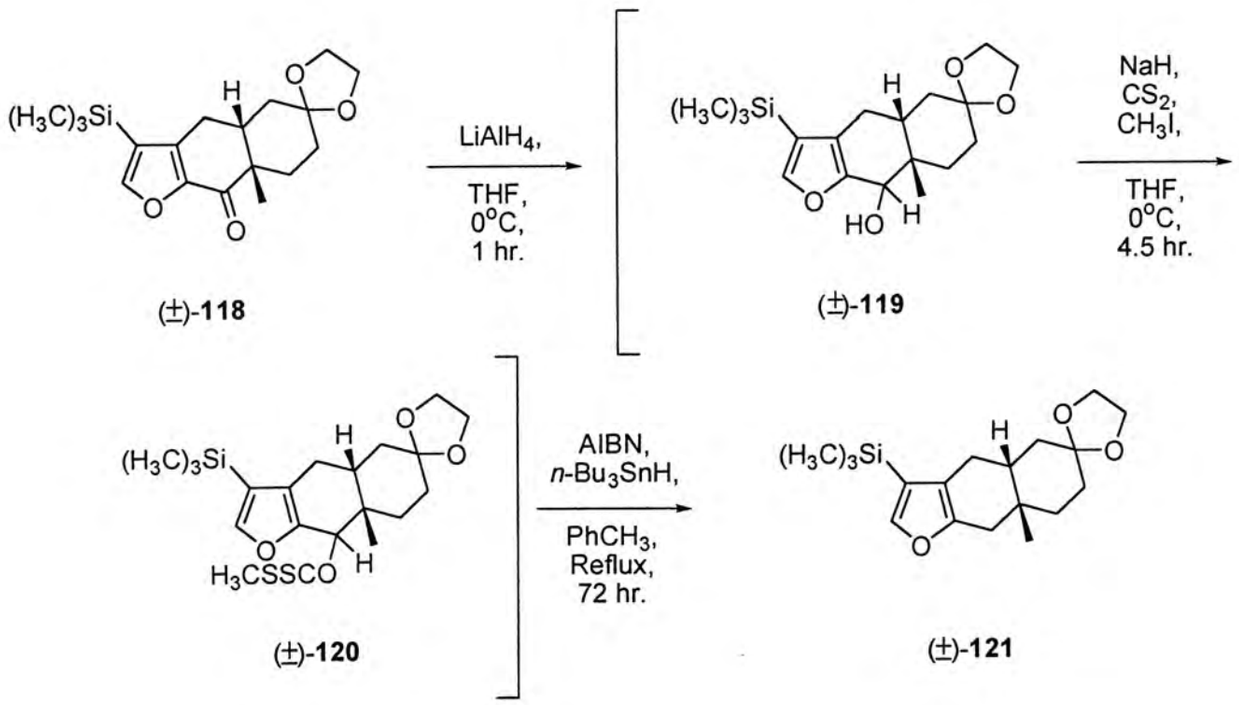


Figure 11. ORTEP plot of the enantiomers 4,5,7,8-Tetrahydro-8a-methyl-6,6-(1',3'-dioxolan-2'-yl)-3-(trimethylsilyl)naphtho[2,3-*b*]furan-9-one (**118**).

upfield shift of C-6, C-7 and C-9 protons were due to the replacement of the carbonyl substituent by a ketal substituent. The rest of the data in the ^{1}H NMR spectrum concurred with the structure. Sixteen carbon emissions were shown in the ^{13}C NMR spectrum. Furthermore, the disappearance of δ 210.3 and the appearance of δ 64.1, 64.2 and 108.8 in the ^{13}C NMR spectrum in comparison with the ^{13}C NMR spectrum of compound **117** substantiated the formation of the ketal substituent. The elemental analysis also supported the formula of the compound.

Several experiments were attempted in the conversion of the trimethylsilyl substituent on the C ring of compound **118** into a methyl substituent.[51-55,81-84] However, no positive result was secured.



Scheme 15 Removal of carbonyl substituent in compound **118**.

A three-step Barton-McCombie radical deoxygenation procedure[45] was employed to remove the carbonyl on ring B. Thus, reduction of compound **118** with lithium aluminum hydride yielded a diastereomeric mixture of alcohol **119**, which

was converted to xanthate **120**. Tributyltin hydride and AIBN were used to perform the free radical reaction in the removal of the xanthate substituent on B ring, providing compound **121** (Scheme 15).

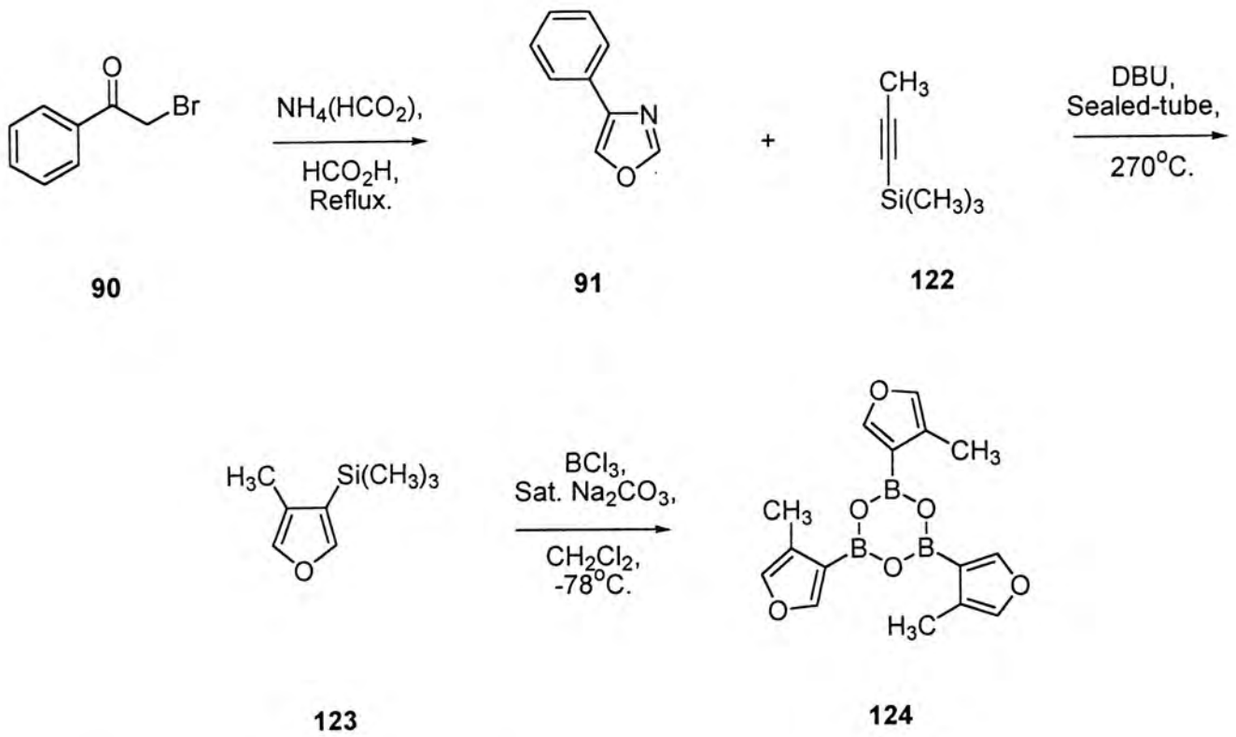
Alcohol **119** and xanthate **120** presented very complex ^{1}H NMR and ^{13}C NMR spectra, due to the fact that their diastereomers could not be separated by column chromatography. The formulae of alcohol **119** and xanthate **120** were supported by elemental analyses and high resolution mass spectral analyses, respectively. The ^{1}H NMR spectrum of **121** indicated three singlets at δ 0.19, 0.98 and 7.14, which represented the trimethylsilyl protons, the methyl protons, and the furan α-proton, respectively. The ketal substituent showed a multiplet of 4H between δ 3.87 and 4.01. The protons at C-4 appeared at δ 2.09. The protons at C-1 appeared as a multiplet between δ 2.70 and 2.89. The rest of the protons appeared as a multiplet between δ 1.36 and 1.92. In comparison of the ^{1}H NMR spectrum of compound **121** with the ^{1}H NMR spectrum of compound **118**, the ^{1}H NMR spectrum of **121** clearly indicated two additional protons between δ 1 and 3.5 for the two newly formed protons at C-4. An upfield shift of the furan α-proton of compound **121** was resulted due to the disappearance of the deshielding effect induced by the carbonyl substituent on B ring. The upfield shift of all protons of compound **121** in comparison with compound **118** also indicated the absence of carbonyl substituent on B ring. Moreover, the disappearance of δ 189.7 and the appearance of δ 37.7 in the ^{13}C NMR spectrum in comparison with the ^{13}C NMR spectrum of compound **118** also indicated the removal of carbonyl substituent on B ring. Sixteen carbon emissions were shown in the ^{13}C NMR spectrum. Lastly, the high resolution mass spectral result also supported the formula of the compound.

When the carbonyl substituent on B ring was removed, several experiments were attempted in the conversion of the trimethylsilyl substituent on the C ring of compound **121** into a methyl substituent.[51-59] Again, no positive result was secured. This result led us to devise another route. The whole synthetic scheme was repeated with a methyl substituent on C ring, so a subsequent conversion of the trimethylsilyl substituent on C ring into methyl substituent was not necessary. The new synthetic pathway will be delineated in the following section.

2.3 C ring + A ring → AC ring → ABC ring Scheme B

2.3.1 Preparation of C ring in Scheme B

Tris(4-methylfuran-3-yl)boroxine (**124**)[52,85] was the precursor of C ring. 4-Phenyloxazole (**91**)[60,63] was synthesized from 2-bromoacetophenone (**90**)[63]. The Diels-Alder reaction between 4-phenyloxazole (**91**)[60,63] and 1-trimethylsilyl-1-propyne (**122**) gave **123**. 4-Methyl-3-trimethylsilylfuran (**123**)[52,85] was then converted to tris(4-methylfuran-3-yl)boroxine (**124**)[52,85] (Scheme 16).



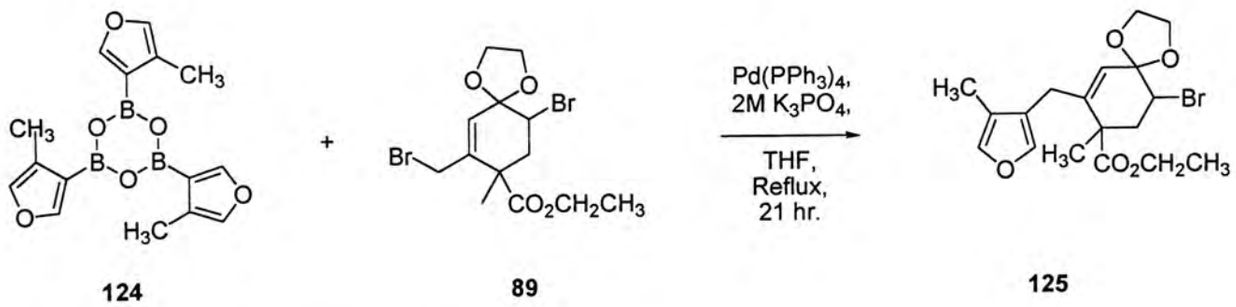
Scheme 16 Synthesis of tris(4-methylfuran-3-yl)boroxine.

2.3.2 Preparation of A ring in Scheme B

The precursor of A ring was the functionalized Hagemann's ester **89**, because it underwent Suzuki cross-coupling[57-59] efficiently and was used in the C ring + A ring → AC ring → ABC ring approach. The synthesis of the functionalized Hagemann's ester **89** was already shown in Scheme 9.

2.3.3 Formation of B ring in Scheme B

When the precursors of A ring and C ring were realized, cyclization of B ring was then performed. Suzuki cross-coupling[57-59] of tris(4-methylfuran-3-yl)boroxine (**124**)[52,85] with functionalized Hagemann's ester **89** in aqueous potassium phosphate and tetrakistriphenylphosphine palladium(0) catalyst generated compound **125** (Scheme 17). The elemental analysis and high resolution mass spectrum agreed with the structure of **125**. Compound **125** was produced as a diastereomeric mixture in a ratio of 7 to 3. Compound **125** exhibited very complex ^{1}H NMR and ^{13}C NMR spectra. ^{1}H NMR and ^{13}C NMR spectra of compound **125** were similar to compound **110**[50] except for the methyl substituent in C ring. The ^{1}H NMR emission of the methyl substituent in compound **125** indicated a singlet at δ 1.86 instead of a singlet at δ 0.20 for the trimethylsilyl substituent in compound **110**. The ^{13}C NMR emission of the methyl substituent in compound **125** appeared at δ 7.8.



124 **89** **125**

Scheme 17 Suzuki cross-coupling of **89** and **124**.

The undesirable homo-coupling appeared when Suzuki cross-coupling[57-59] of tris(4-methylfuran-3-yl)boroxine (**124**)[52,85] with functionalized Hagemann's esters **89**, and led to 4,4'-dimethyl-3,3'-bifuran. The catalytic cycle and mechanism were proposed by Poetsch (Figure 12).[50] The first formation of palladium-borate complex, the electrophilic attack of palladium(II), the four-centered transmetallation, and the

complex disintegration led to the undesirable homo-coupling of alkyl boronates.[50] The undesirable homo-coupling was solved by the addition of boroxine **124** into a solution of compound **89** and catalyst. This method undoubtedly increased the yield of **125**.

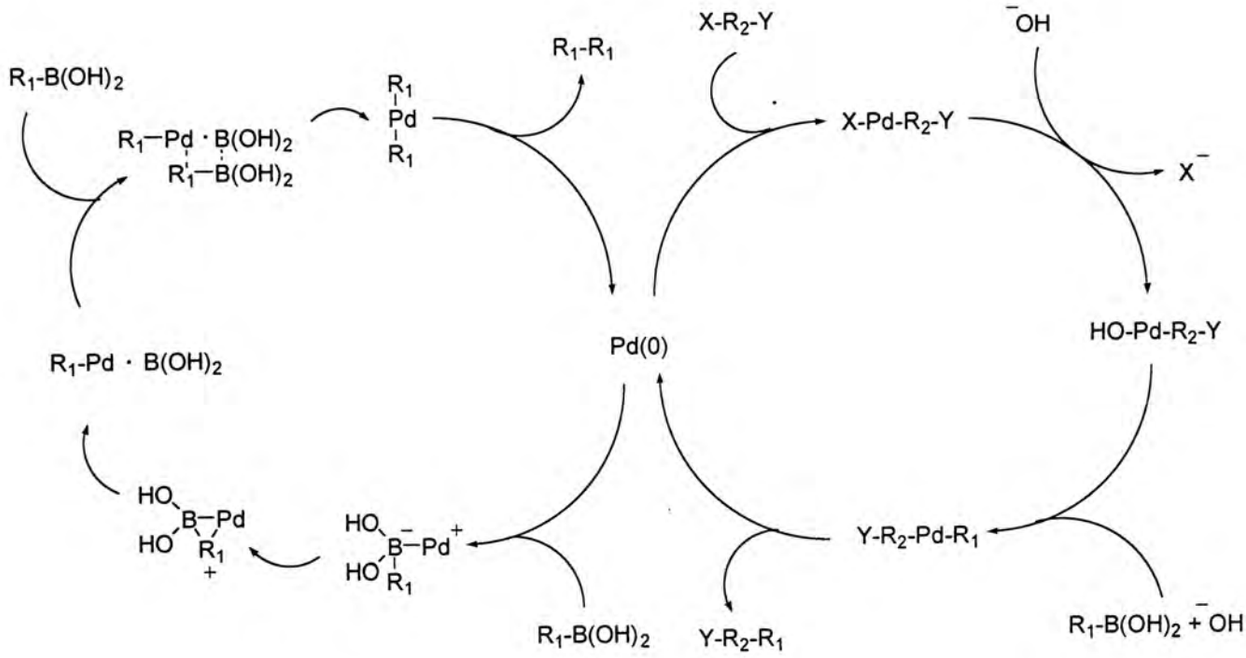
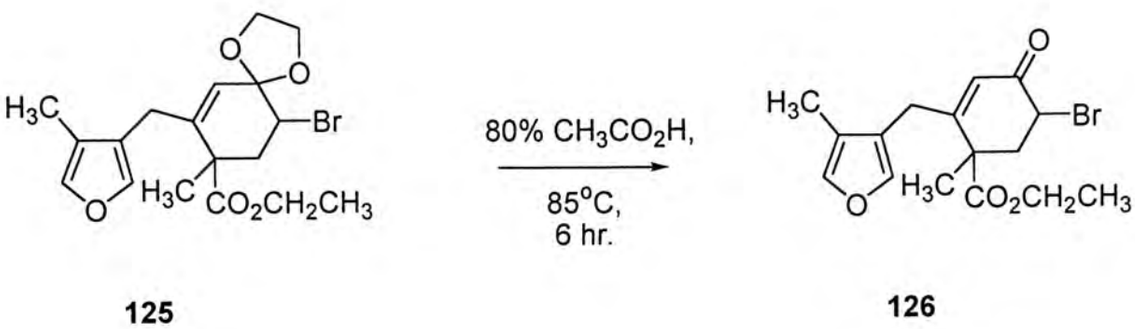


Figure 12. Catalytic cycle of Suzuki cross-coupling and undesirable homo-coupling reactions proposed by Poetsch.

Deprotection of ketal group in compound **125** with 80% acetic acid was performed prior to the removal of the bromide substituent. Bromoenone **126** was produced as a diastereomeric mixture in a ratio of 4 to 1 (Scheme 18). Compound **126** decomposed readily, under explosure to air at room temperature, or under sunlight. Compound **126** presented very complex ^{1}H NMR and ^{13}C NMR spectra. Compound **126** showed similar ^{1}H NMR and ^{13}C NMR spectra to compound **111**[50] except for the methyl substituent in C ring. The ^{1}H NMR signal of the methyl substituent in compound **126** showed a singlet at δ 1.83 instead of a singlet at δ 0.16 for the trimethylsilyl substituent in compound **111**. The ^{13}C NMR emission of the methyl substituent in compound **126** appeared at δ 7.9. Furthermore, the disappearance of a

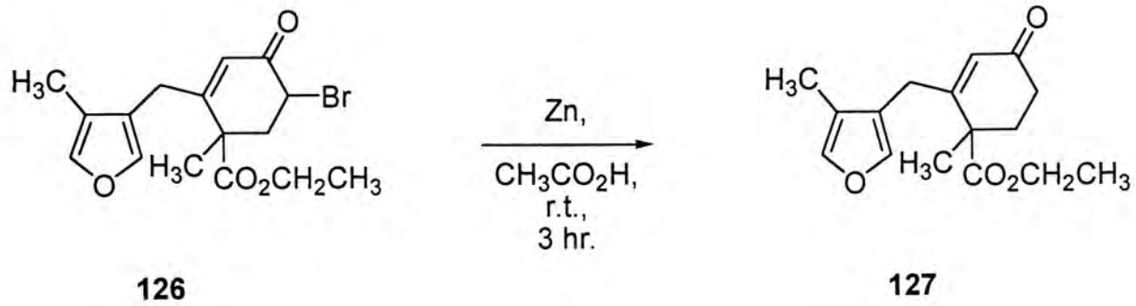


125 **126**

Scheme 18 Deprotection of ketal substituent in compound **125**.

multiplet between δ 4.04 and 4.23 in the ^{1}H NMR spectrum of **126** in comparison with the ^{1}H NMR spectrum of **125** showed the removal of the ketal substituent. The disappearance of δ 65.8, 65.9, 66.4, 66.5 and 104.5, and the appearance of δ 190.0 and 190.8 in the ^{13}C NMR spectrum of **126** in comparison with the ^{13}C NMR spectrum of compound **125** also indicated the removal of the ketal substituent and the formation of the carbonyl substituent. The elemental analysis also supported the formula of bromoenone **126**.

Reformatsky reaction of **126** in the presence of zinc dust in glacial acetic acid successfully removed the undesirable bromide substituent and provided enone **127** (Scheme 19). Compound **127** showed similar ^{1}H NMR and ^{13}C NMR spectra to compound **112**[50] except the methyl substituent in C ring. The ^{1}H NMR emission of the methyl substituent in compound **127** indicated a long range proton-proton coupling with the α-proton of furan and appeared as a doublet at δ 1.86 instead of a singlet at δ 0.16 for the trimethylsilyl substituent in compound **112**. The ^{13}C NMR spectrum of the methyl substituent in compound **127** appeared at δ 7.8. Moreover, the disappearance of a doublet of doublets at δ 4.93 and the appearance of a multiplet between δ 2.33 and 2.64 in the ^{1}H NMR spectrum of **127** in comparison with the ^{1}H NMR spectrum of **126** showed the removal of bromide substituent. The disappearance

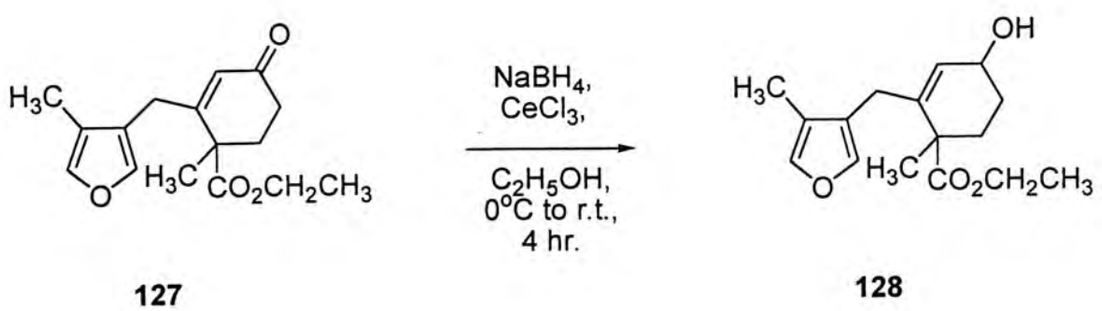


126 **127**

Scheme 19 Removal of bromide substituent in compound **126**.

of δ 48.8 and the appearance of δ 34.7 in the ^{13}C NMR spectrum of **127** in comparison with the ^{13}C NMR spectrum of **126** also showed the removal of the bromide substituent. The elemental analysis again supported the formula of enone **127**.

Reduction of the carbonyl into hydroxyl was attempted before cyclization. Thus, reduction of enone **127** proceeded smoothly with sodium borohydride and cerium(III) chloride in ethanol, providing alcohol **128** as a diastereomeric mixture (Scheme 20). However, the diastereomeric mixture of **128** could not be separated by column chromatography. Moreover, compound **128** showed similar ^{1}H NMR and ^{13}C NMR spectra to compound **113**[50] except for the methyl substituent in C ring. The ^{1}H NMR signal of the methyl substituent in compound **128** indicated a singlet at δ 1.86 instead of a singlet at δ 0.19 for the trimethylsilyl substituent in compound **113**. The ^{13}C NMR signal of the methyl substituent in compound **128** appeared at δ 8.0 instead

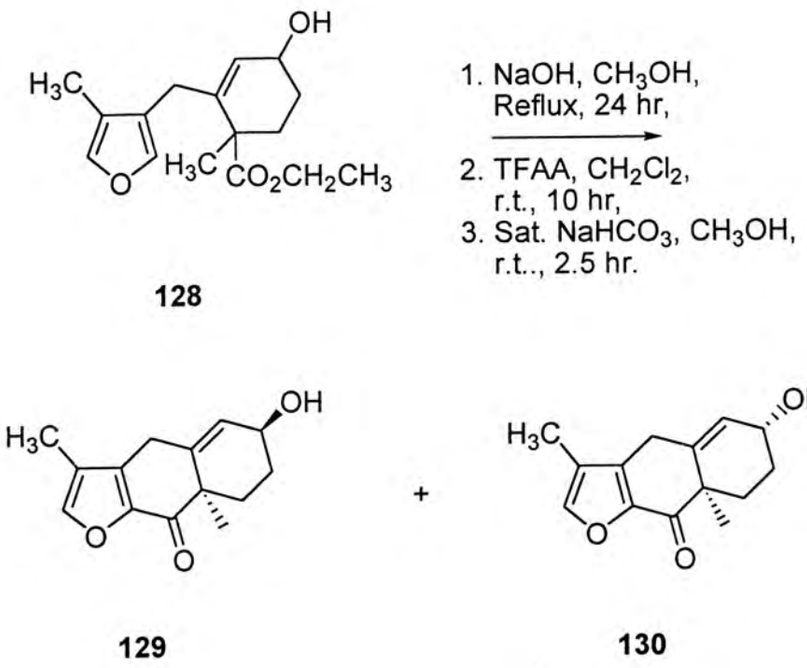


127 **128**

Scheme 20 Reduction of compound **127**.

of δ -0.5 for the trimethylsilyl substituent in compound **113**. Furthermore, The disappearance of δ 198.4 and the appearance of δ 65.6 and 65.7 in the ^{13}C NMR spectrum of compound **128** in comparison with the ^{13}C NMR spectrum of compound **127** indicated the removal of carbonyl substituent and the formation of an alcohol substituent. The elemental analysis supported the formula of compound **128**.

The cyclization of compound **128** involved three steps. Thus, base hydrolysis of the ester moiety with sodium hydroxide was followed by a Friedel-Crafts acylation, and the hydrolysis of the trifluoroacetate intermediate. In this way, two diasteromers **129** and **130** was furnished, which were separated by column chromatograpy (Scheme 21).

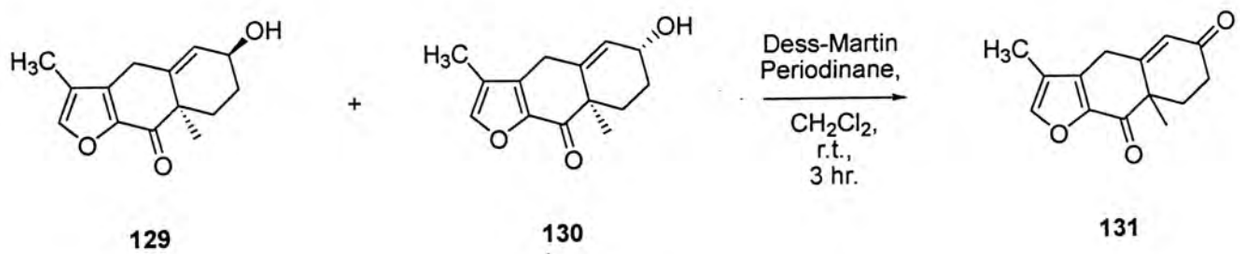


Scheme 21 Cyclization of compound **128**.

Diastereomers **129** and **130** showed similar ^{1}H NMR and ^{13}C NMR spectra to compounds **114** and **115**[50] except for the methyl substituent in C ring. The ^{1}H NMR emission of the methyl substituent in compound **129** indicated a singlet at δ 2.00. The

^{1}H NMR emission of the methyl substituent in compound **130** showed a long range proton-proton coupling with the α-proton of furan and indicated a doublet at δ 1.98. On the other hand, the ^{13}C NMR emission of the methyl substituent in compound **129** appeared at δ 7.7 instead of δ -0.9 for the trimethylsilyl substituent in compound **114**. Moreover, the disappearance of δ 14.1, 60.8, 60.9 and 176.1, and the appearance of δ 189.0 and 189.6 in the ^{13}C NMR spectra of compounds **129** and **130** in comparison with the ^{13}C NMR spectrum of compound **128** showed the removal of ester substituent and the formation of carbonyl substituent. The high resolution mass spectra supported the formulae of compounds **129** and **130**. With a pair of cyclized diastereomers **129** and **130** in hand, transformations of functional groups in different order were sought.

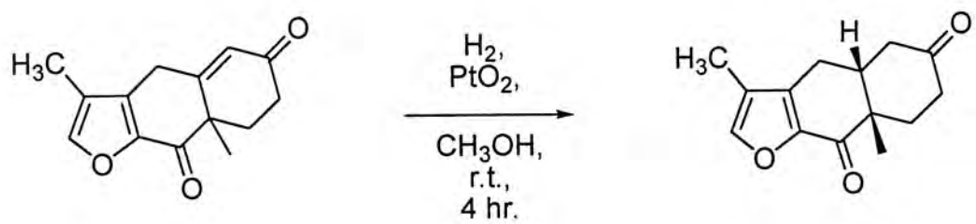
Dess-Martin periodinane oxidation[71-73] converted the pair of diastereomers **129** and **130** into a single enone **131** (Scheme 22). The highly acidic methylene protons on B ring led to a $\Delta^{1,10}$ isomer along with compound **131** in the ratio 4 to 1 during column purification on silica gel. Compound **131** showed similar ^{1}H NMR and ^{13}C NMR spectra to compound **116**[50] except for the methyl substituent in C ring. Furthermore, the high resolution mass spectral result supported the formula of **131**.



129 **130** **131**

Scheme 22 Oxidation of diastereomers **129** and **130**.

Compound **132** was furnished by hydrogenation of the α,β-unsaturated ketone **131** and its $\triangle^{1,10}$ isomer. Thus, hydrogenation on Adams' catalyst[74-75] in methanol at room temperature was chosen (Scheme 23). The ^{1}H NMR spectrum of **132** indicated three singlets at δ 1.32, 1.99 and 7.43, which represented the methyl protons, the furan β-methyl protons and the furan α-proton, respectively. The proton at C-10 was displayed at δ 1.51, while the protons at C-1 appeared at δ 2.66 and 3.04. A multiplet between δ 2.23 and 2.59 indicated the presence of other protons. The ^{13}C NMR spectrum showed 14 types of carbons. Two carbonyl carbons were found at δ 188.5 and 210.5. The furan carbons appeared at δ 121.4, 135.7, 145.3 and 145.6. The furan β-methyl carbon appeared at δ 7.7. The methyl carbon was placed at δ 24.8. The C-1, C-6, C-10, C-7, C-9 and C-5 carbons appeared at δ 23.6, 33.0, 38.7, 44.0, 44.5, and 46.8, respectively. Furthermore, compound **132** showed similar ^{1}H NMR and ^{13}C NMR spectra to compound **117** except for the methyl substituent in C ring.



131 (±)-**132**

Scheme 23 Hydrogenation of compound **131**.

The configuration between the proton at C-10 and the methyl substituent at C-5 of compound **132** was determined by the ^{1}H-^{1}H NOESY NMR spectroscopic analysis. The *cis*-configuration between the proton at C-10 and the methyl substituent

at C-5 was shown, because the methyl protons at C-5 (δ 1.32) correlated with H_2O and the proton at C-10 (δ 1.51) (Figures 13 and 14).

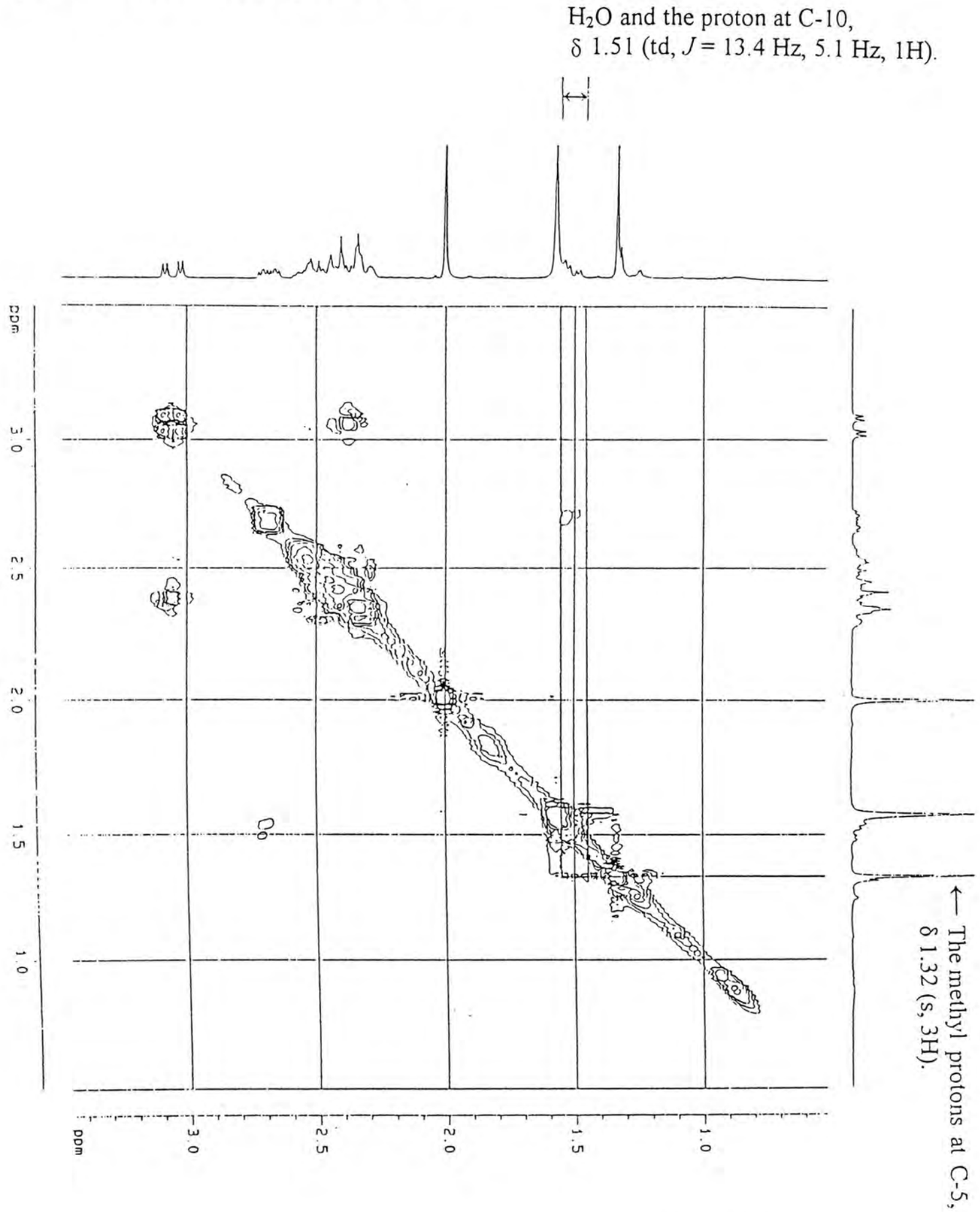
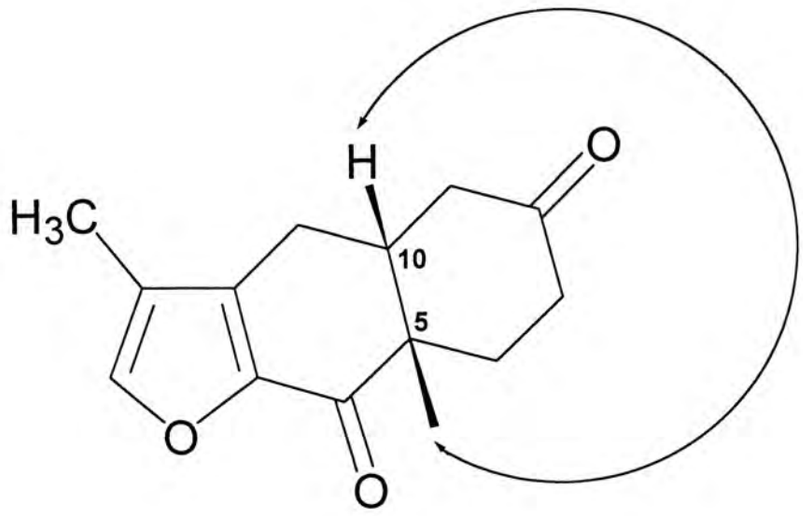


Figure 13. NOESY spectrum of 4,5,7,8-Tetrahydro-3,8a-dimethylnaphtho[2,3-*b*]furan-6(4*H*),10(8a*H*)-dione (**132**).

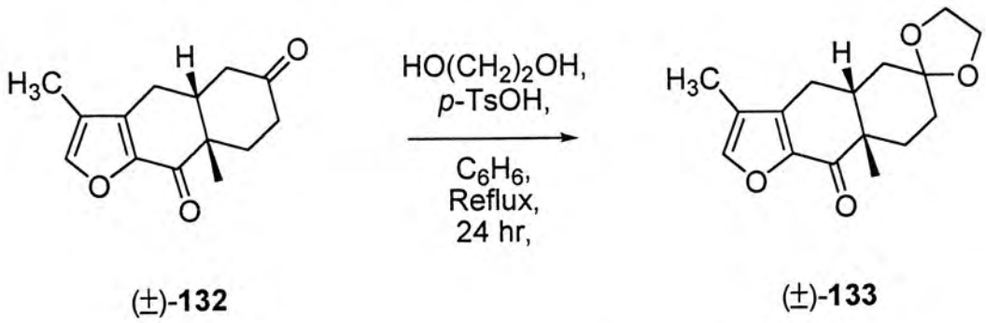


(±)-**132**

Figure 14. Compound **132** with arrows represented NOE enhancements.

Protection of the carbonyl group on A ring of compound **132** with ethylene glycol in refluxing benzene yielded a protected compound **133** (Scheme 24). The ^{1}H NMR spectrum of **133** indicated a multiplet of 4H between δ 3.85 and 3.96 for the newly formed ketal substituent. The upfield shift of C-6, C-7 and C-9 protons were due to the replacement of the carbonyl substituent by a ketal substituent. The rest of the data in ^{1}H NMR spectrum concurred with the structure. Sixteen carbon absorptions were shown in the ^{13}C NMR spectrum. Furthermore, the disappearance of δ 210.5 and the appearance of δ 64.2, 64.3 and 108.9 in the ^{13}C NMR spectrum in comparison with the ^{13}C NMR spectrum of compound **132** substantiated the formation of the ketal substituent. On the other hand, compound **133** showed similar ^{1}H NMR and ^{13}C NMR spectra to compound **118** except the methyl substituent in C ring. The ^{1}H NMR signal of the methyl substituent in compound **133** indicated a long range proton-proton coupling with the α-proton of furan and appeared as a doublet at δ 1.96 instead of a doublet at δ 0.18 for the trimethylsilyl substituent in compound **118**. The ^{13}C NMR emission of the methyl substituent in compound **133** appeared at δ

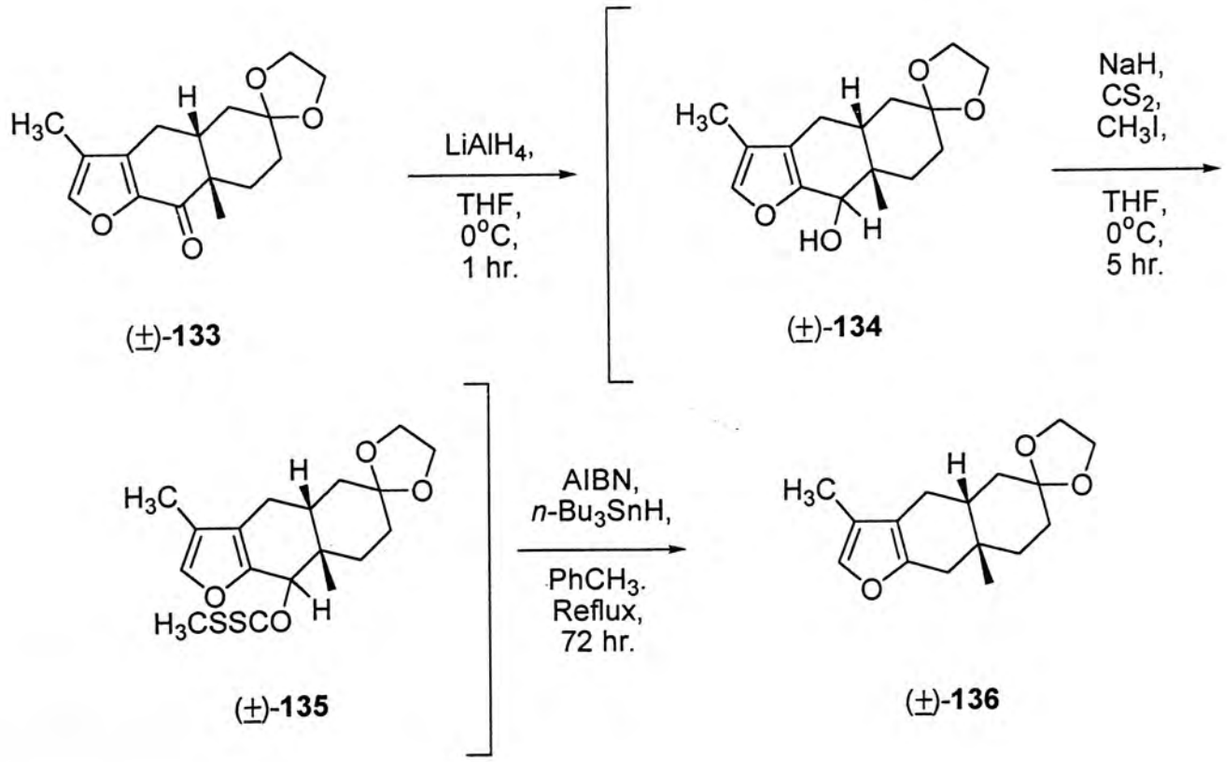
7.7 instead of δ -1.0 for the trimethylsilyl substituent in compound **118**. The elemental analysis also supported the formula of the compound.



(±)-**132** (±)-**133**

Scheme 24 Protection of carbonyl substituent in compound **132**.

A three-step Barton-McCombie radical deoxygenation procedure[45] was employed to remove the carbonyl on Ring B. Thus, reduction of compound **133** with lithium aluminum hydride yielded a diastereomeric mixture of alcohol **134**, which



(±)-**133** (±)-**134**

(±)-**135** (±)-**136**

Scheme 25 Removal of carbonyl substituent in compound **133**.

was converted to xanthate **135**. Tributyltin hydride and AIBN were used to perform the free radical reaction in the removal of the xanthate substituent on B ring, providing compound **136** (Scheme 25). Alcohol **134** and xanthate **135** presented very complex ^{1}H NMR and ^{13}C NMR spectra, due to the fact that their diastereomers could not be separated by column chromatography. The formulae of alcohol **134** and **135** were supported by elemental analyses and high resolution mass spectral analysis, respectively.

The ^{1}H NMR spectrum of compound **136** indicated three singlets at δ 0.97, 1.90 and 7.04, which represented the methyl protons, the furan β-methyl protons and the furan α-proton, respectively. The ^{1}H NMR spectrum of compound **136** exhibited a multiplet of 4H between δ 3.84 and 4.03 for the newly formed ketal substituent. The protons at C-4 appeared at δ 2.01, while the protons at C-1 appeared at δ 2.62 and 2.78. A multiplet between δ 1.37 and 1.92 indicated the presence of other protons. An upfield shift of the furan α-proton of compound **136** was found due to the disappearance of the deshielding effect caused by the carbonyl substituent on B ring. In comparison of the ^{1}H NMR spectrum of compound **136** with the ^{1}H NMR spectrum of compound **133**, the ^{1}H NMR spectrum of **136** clearly indicated two additional protons between δ 1 and 3.5 for the two newly formed protons at C-4. Moreover, the upfield shift of all protons of compound **136** in comparison with compound **133** also indicated the removal of carbonyl substituent on B ring. The disappearance of δ 189.6 and the appearance of δ 37.7 in the ^{13}C NMR spectrum in comparison with the ^{13}C NMR spectrum of compound **133** also substantiated the removal of the carbonyl substituent on B ring. On the other hand, compound **136** showed similar ^{1}H NMR and ^{13}C NMR spectra to those compound **121** except for the methyl substituent in C ring. The ^{1}H NMR emission of the methyl substituent of compound **136** showed a singlet at

δ 1.90 instead of δ 0.19 for the trimethylsilyl substituent in compound **121**. The ^{13}C NMR signal of the methyl substituent of compound **136** appeared at δ 8.1 instead of δ -0.7 for the trimethylsilyl substituent in compound **121**. The high resolution mass spectral result also supported the formula of compound **136**.

Compound **137** was furnished by a dilute acid deprotection of the ketal substituent in compound **136** (Scheme 26). The experiment was done with great precaution because compounds **136** and **137** decomposed readily upon heating. Several experiments were attempted to deprotect the ketal substituent, such as dilute acetic acid in room temperature or at oil bath temperature of 85°C. However, no positive result was obtained. Eventually, the ketal group was removed upon treatment of **136** with dilute HCl at room temperature.

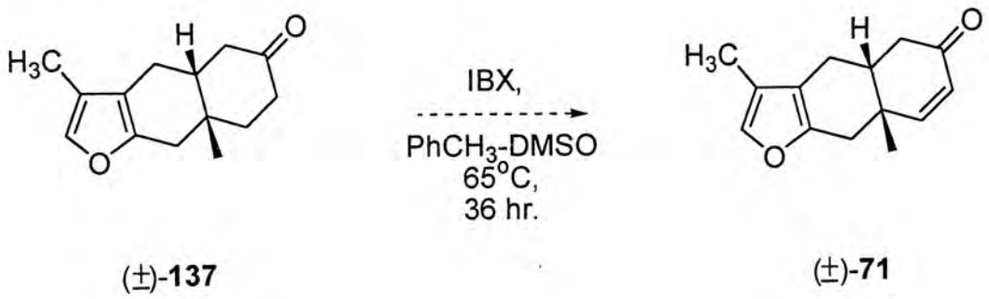
(±)-**136** (±)-**137**

Scheme 26 Deprotection of compound **136**.

The ^1H NMR spectrum of compound **137** exhibited three singlets in δ 1.14, 1.93 and 7.17, which represented the methyl protons at C-5, the furan β-methyl protons, and the furan α-proton, respectively. The disappearance of a multiplet between δ 3.84 and 4.03 in the ^1H NMR spectum of compound **137** indicated the removal of the ketal substituent. Furthermore, the downfield shift of C-7 and C-9 protons were due to the replacement of the ketal substituent by a carbonyl substituent.

The disappearance of δ 64.1, 64.2 and 109.5 and the appearance of δ 211.7 in the ^{13}C NMR spectrum of compound **137** also showed the removal of the ketal substituent and the formation of a carbonyl substituent. The high resolution mass spectral result also supported the formula of compound **137**.

o-Iodoxybenzoic acid should be able to convert **137** into compound **71** (Scheme 27).[86] After this oxidation, a compound was obtained with the appearance of



(±)-**137** (±)-**71**

Scheme 27 Alkene formation of compound **137**.

two doublets at δ 5.93 and 6.84 in its crude ^{1}H NMR spectral analysis of compound **71** indicated an alkene formation. The appearance of two singlets at δ 1.97 and δ 7.09 showed the furan β-methyl protons and the furan α-proton, respectively. A low resolution mass spectral result indicated the molecular weight of 216 as a preliminary confirmation of the compound. The overall reaction yield was very low, so that no concrete evidence for the formation of **71** could be obtained. It is worthy to note that **71** was the key intermediate in Kanematsu's synthesis[43] of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) (Schemes 4 and 5).

CHAPTER 3 CONCLUSION

Compound **137** was successfully prepared through a C ring + A ring → AC ring → ABC ring approach. It may eventually lead to the natural products tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) after several functional group transformations exactly identical to the procedures developed by Kanematsu.[43] The routes so far established proved that our own organosilicon-organoboron protocol was useful in the synthesis of sesquiterpenoid furanoeudesmanes.

Compound **121** with a furan β-trimethylsilyl substituent in C ring was made through an eleven step procedure starting from compounds **88** and **89** (Schemes 11-15). During the route towards the target, an X-ray crystallography analysis of compound **118** confirmed the *cis*-configuration between the C-5 and C-10 carbons (Figure 11). On the other hand, Compound **137** with a furan β-methyl substituent in C ring required twelve steps for its realization, starting from compounds **89** and **124** (Schemes 17-27). The ^{1}H-^{1}H NOESY NMR spectroscopic analysis also proved that compound **132** was of *cis*-configuration between the C-5 and C-10 carbons (Figures 13-14).

The formal syntheses of tubipofuran (**20**) and 15-acetoxytubipofuran (**21**) were not completed. It is hoped that compound **137** could serve as a pivatol compound towards the realization of **20** and **21**.

CHAPTER 4 EXPERIMENTAL SECTION

General information

All analytical graded reagents and solvents were chosen, further purification and drying by standard methods were followed whenever necessary. Rotary evaporators were good for the evaporation of organic solvents. Column chromatography was performed on E. Merck silica gel (230-400 mesh) or Qingdao Haiyang silica gel (200-300 mesh). Thin-layer chromatography (TLC) was performed on E. Merck silica gel 60 F_{254} (0.25 mm thickness) precoated on aluminum plates. Compounds on TLC plate were visualized under both long (365 nm) and short (254 nm) UV light, a spray of 5% w/v dodecamolybdophosphoric acid in ethanol with subsequent heating, and a spray of 5% w/v potassium permanganate in 1% v/v sulphuric acid solution.

Melting points were measured on a Reichert Microscope apparatus and were uncorrected. NMR spectra were recorded on a Bruker DPX-300 spectrometer (75.47 MHz for ^{13}C and 300.13 MHz for ^{1}H). All samples were prepared at room temperature in deuterated chloroform solution. Chemical shifts are stated as parts per million (ppm) and in δ unit relative to the resonance of $CDCl_3$ (7.26 ppm in ^{1}H and 77.00 ppm for the central line of the triplet in ^{13}C mode, respectively). Coupling constants (*J*) are displayed in Hz. Abbreviations (s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet) for corresponding splitting patterns are used. ^{1}H NMR are reported in this order: chemical shift; multiplicity; coupling constants(s); number(s) of proton. Mass spectra (EIMS and HRMS) attained with a HP 5989B spectrometer at 70eV ionizing voltage. Elemental analyses were examined either at MEDAC LTD, United Kingdom or at Shanghai Institute of Organic Chemistry, The Chinese Academy of Sciences, China. X-ray analyses were obtained by SHELXTL PLUS (PC

Version) with P4 X-ray four circle diffractometer.

2-Bromoacetophenone (90).[63] To a solution of acetophenone (772.52 g, 6.43 mol) in glacial acetic acid (1200 mL) stirred under ice water bath 0°C, was added bromine (331.35 mL, 6.43 mol) for 3 hr at 5-10°C. The reaction mixture was then poured into ice water. After filtration, pale yellow solids were washed with ice-water, and dried. Further purification by recrystallization from ethanol yielded **90** (691.08 g, 54%) as white solids; m.p. 47-49°C [lit.[63] m.p. 48-51°C]; ^{1}H NMR ($CDCl_3$) δ 4.46 (s, 2H), 7.46–7.51 (m, 2H), 7.57–7.63 (m, 1H), 7.96–7.99 (m, 2H).

4-Phenyloxazole (91).[60,63] A mixture of **90** (392.23 g, 1.97 mol), ammonium formate (431.39 g, 6.84 mol), and formic acid (1600 mL) was refluxed for 4 hr. Upon removal of formic acid under reduced pressure, the residue was then neutralized to *p*H 8 by saturated NaOH solution, extracted with Et_2O (3 x 1000 mL). The combined organic layer was dried over $MgSO_4$, and concentrated under reduced pressure. Vacuum distillation at 68-94°C / 0.1 mmHg [lit.[63] b.p. 57-60°C / 0.6 mmHg] gave a pale yellow oil. Further purification by column chromatography on silica gel (1250 g, hexane-Et_2O, 6:1) gave **91** (94.40 g, 33%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 7.22–7.41 (m, 3H), 7.72–7.75 (m, 2H), 7.87 (s, 1H), 7.89 (s, 1H).

Bis(trimethylsilyl)acetylene (92).[64-65] To a stirred mixture of ethyl bromide (218.02 g, 2.01 mol), magnesium (50.03 g, 2.06 mol) in THF (1200 mL) was passed through a stream of acetylene gas at 25°C for 6 hr. Chlorotrimethylsilane (217.13 g, 1.99 mol) was then added dropwise for 3.5 hr. The reaction was then stirred for 8 hr. A cold saturated NH_4Cl solution (600 mL) was subsequently added to the reaction mixture

under ice bath 0°C. Organic layer was then washed with cold saturated NH_4Cl solution, dried over $MgSO_4$. Further purification by distillation at 136-138°C / 760 mmHg [lit.[64] b.p. 136-137°C / 760 mmHg] delivered **92** (122 g, 71%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.18 (d, J = 3.0 Hz, 18H).

3,4-Bis(trimethylsilyl)furan (93).[51-55] A mixture of **91** (14.52 g, 0.1 mol), **92** (17.04 g, 0.1 mol), and 1,8-diazabicyclo[5.4.0]undec-7-ene (2.28 g, 0.02 mol) was placed in a sealed-tube and then heated to 270°C for 7 days. Vacuum distillation of the reaction mixture at 40-60°C / 28 mmHg [lit.[53] b.p. 30-32°C / 0.6 mmHg] and further purification of the distillate by column chromatography on silica gel (450 g, hexane) gave **93** (15.72 g, 74%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.26 (s, 18H), 7.40 (s, 2H).

4-Methyl-3-trimethylsilylfuran (123).[52,85] A mixture of **91** (21.34 g, 0.15 mol), 1-trimethylsilyl-1-propyne (15.02 g, 0.13 mol), and 1,8-diazabicyclo[5.4.0]undec-7-ene (3.05 g, 0.02 mol) was placed in a sealed-tube and then heated to 270°C for 7 days. Vacuum distillation of the reaction mixture at 30-47°C / 28 mmHg [lit.[52] bath temperature 30-60°C / 65-80 pa] and further purification of the distillate by chromatography on silica gel (620 g, pentane) offered **123** (14.59 g, 71%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.16 (s, 9H), 2.00 (s, 3H), 7.16 (s, 2H).

Tris[4-(trimethylsilyl)furan-3-yl]boroxine (88).[51-55] To a solution of **93** (15.02 g, 70.75 mmol) in anhydrous CH_2Cl_2 (408 mL) was added a solution of BCl_3 (1.0 M) in CH_2Cl_2 (92 mL) at -78°C under nitrogen atmosphere. The reaction mixture was allowed to stir at -78°C for 6 hr, quenched with saturated Na_2CO_3 solution until pH 10.

After returning to 27°C, the reaction mixture was extracted with Et_2O (3 x 250 mL), the combined organic layer was dried over $MgSO_4$, and the solvent was evaporated under reduced pressure. The residue was column chromatographed on silica gel (315 g, hexane-EtOAc, 3:2) to furnish **88** (9.28 g, 79%) as colorless crystals; m.p. 167–168°C [lit.[52] m.p. 167-168°C]; ^{1}H NMR ($CDCl_3$) δ 0.37 (s, 27H), 7.43 (d, J = 1.0 Hz, 3H), 8.19 (d, J = 1.0 Hz, 3H).

Tris(4-methylfuran-3-yl)boroxine (124).[52,84] To a solution of **123** (21.97 g, 0.14 mol) in anhydrous CH_2Cl_2 (640 mL) was added a solution of BCl_3 (1.7 M) in CH_2Cl_2 (242 mL) at -78°C under nitrogen atmosphere. The reaction mixture was allowed to stir at -78°C for 6 hr, quenched with saturated Na_2CO_3 solution until *p*H 10. After returning to 27°C, the reaction mixture was extracted with Et_2O (3 x 500 mL), the combined organic layer was dried over $MgSO_4$, and the solvent was evaporated under reduced pressure. The residue was column chromatographed on silica gel (400 g, hexane-EtOAc, 2:1) to afford **124** (10.29 g, 67%) as semi solids, m.p. 130-131°C [lit.[52] m.p. 130-131°C]; ^{1}H NMR ($CDCl_3$) δ 2.23 (s, 9H), 7.23 (s, 3H), 7.90 (d, J = 1.0 Hz, 3H).

Ethyl 1,2-dimethyl-4-oxocyclohex-2-ene-1-carboxylate (102).[66] A solution of ethyl 2-acetyl-2-methyl-5-oxo-hexanote[66] (67.80 g, 0.32 mol), piperidine (15.65 mL, 0.16 mol), glacial acetic acid (18.11 mL, 0.32 mol), and anhydrous benzene (787 mL) was refluxed for 24 hr with a Dean-Stark apparatus. After cooling to room temperature, the reaction mixture was then washed with water (700 mL), brine (700 mL), and dried over $MgSO_4$. Upon removal of solvent under reduced pressure, the residue was purified by vacuum distillation at 102-108°C / 0.1 mm Hg [lit.[66] b.p. 110°C / 0.4 mmHg] to deliver a pale yellow oil. Further purification by column chromatography

Ethyl 5-bromo-2-bromomethyl-4-(1,3-dioxolan-2-yl)-1-methyl-cyclohex-2-ene-1-carboxylate (89).[50] A solution of **103** (189.44 g, 0.54 mol), anhydrous benzene (1250 mL), ethylene glycol (300.03 mL, 5.35 mol), and *p*-toluenesulfonic acid monohydrate (61.07 g, 0.32 mmol) was refluxed for 45 hr with a Dean-Stark apparatus. After cooling to room temperature, the reaction mixture was diluted with EtOAc (1000 mL), then washed successively with saturated $NaHCO_3$ solution (1200 mL), water (1200 mL), and brine (1200 mL). The organic solution was dried over $MgSO_4$. After removal of solvent under reduced pressure, the residue was purified by column chromatography on silica gel (1200 g, hexane-EtOAc, 5:1) to furnish **89** (187.46 g, 88%) as a colorless oil, which consisted of a pair of diastereomers. NMR data of the major component: ^{1}H NMR ($CDCl_3$) δ 1.27 (t, J = 7.2 Hz, 3H), 1.44 (s, 3H), 2.32 (t, J = 13.8 Hz, 1H), 2.59 (dd, J = 13.5 Hz, 3.6 Hz, 1H), 3.78–4.29 (m, 7H), 4.56 (dd, J = 13.8 Hz, 3.6 Hz, 1H), 5.90 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.0, 23.8, 31.0, 43.6, 48.4, 51.8, 61.7, 66.1, 104.2, 131.1, 138.9, 173.6; NMR data of the minor component: ^{1}H NMR ($CDCl_3$) δ 1.27 (t, J = 7.2 Hz, 3H), 1.49 (s, 3H), 2.25 (dd, J = 13.2 Hz, 3.3 Hz, 1H), 2.82 (t, J = 13.2 Hz, 1H), 3.78–4.29 (m, 7H), 4.36 (dd, J = 12.9 Hz, 3.6 Hz, 1H), 5.90 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 14.0, 22.2, 30.3, 42.7, 48.9, 51.0, 61.7, 65.9, 66.5, 104.1, 130.4, 140.1, 173.6.

Ethyl 5-bromo-4-(1',3'-dioxolan-2'-yl)-1-methyl-2-[4-(trimethylsilyl)furan-3-yl]methylcyclohex-2-ene-1-carboxylate (110).[50] A mixture of **89** (23.98 g, 60.22 mmol), **88** (9.99 g, 20.07 mmol), $Pd(PPh_3)_4$ (2.32 g, 2.01 mmol) in THF (114 mL) and an aqueous solution of 2 M K_3PO_4 solution (271 mL) was refluxed under N_2 over 6 hr. THF was evaporated under reduced pressure after filtration. The aqueous residue was next extracted with Et_2O (3 x 250 mL). The combined organic extract was washed

with brine (600 mL), dried over $MgSO_4$, and concentrated under reduced pressure. The residue was column chromatographed on silica gel (300 g, hexane-EtOAc, 9:1) to afford **110** (18.46 g, 67%) as a colorless oil, which consisted of a pair of diastereomers in the ratio of 2:1; Data of the major component: ^{1}H NMR ($CDCl_3$) δ 0.20 (s, 9H), 1.27 (t, J = 7.2 Hz, 3H), 1.37 (s, 3H), 2.34 (t, J = 13.5 Hz, 1H), 2.60 (dd, J = 13.5 Hz, 3.6 Hz, 1H), 3.14 (d, J = 17.4 Hz, 1H), 3.24 (d, J = 17.4 Hz, 1H), 3.94–3.97 (m, 2H), 4.10–4.21 (m, 4H), 4.66 (dd, J = 13.8 Hz, 3.6 Hz, 1H), 5.23 (t, J = 1.5 Hz, 2H), 7.25 (s, 1H), 7.27 (s, 1H); ^{13}C NMR ($CDCl_3$) δ -0.5, 14.1, 24.4, 27.8, 43.7, 48.9, 52.9, 61.4, 65.9, 66.3, 104.6, 119.5, 124.7, 126.5, 141.8, 142.1, 148.5, 174.0; Data of the minor component: ^{1}H NMR ($CDCl_3$) δ 0.20 (s, 9H), 1.26 (t, J = 7.2 Hz, 3H), 1.44 (s, 3H), 2.23 (dd, J = 13.2 Hz, 3.6 Hz, 1H), 2.92 (t, J = 13.5 Hz, 1H), 3.07 (s, 2H), 3.94–3.97 (m, 2H), 4.10–4.21 (m, 4H), 4.41 (dd, J = 13.8 Hz, 3.6 Hz, 1H), 5.17 (t, J = 1.5 Hz, 1H), 7.25 (s, 1H), 7.27 (s, 1H); ^{13}C NMR ($CDCl_3$) δ -0.5, 14.1, 21.6, 27.6, 43.0, 49.7, 52.2, 61.4, 65.7, 66.4, 104.5, 119.5, 124.4, 125.3, 141.8, 143.0, 148.5, 174.0.

Ethyl 5-bromo-1-methyl-4-oxo-2-(4-trimethylsilylfuran-3-yl)methylcyclohex-2-ene-1-carboxylate (111).[50] A solution of **110** (13.46 g, 29.43 mmol) in 80% acetic acid (170 mL) was heated under N_2 to an oil bath temperature of 85°C for 3.5 hr. After removal of acetic acid *in vacuo*, the residue was purified by column chromatography on silica gel (350 g, hexane-EtOAc, 9:1) to offer **110** (9.34 g, 77%) as a colorless oil, which consisted of a pair of diastereomers in a ratio of 9:1; Data of the major component: ^{1}H NMR ($CDCl_3$) δ 0.16 (s, 9H), 1.29 (t, J = 7.2 Hz, 3H), 1.52 (s, 3H), 2.41 (t, J = 13.5 Hz, 1H), 2.95 (dd, J = 13.5 Hz, 5.1 Hz, 1H), 3.46 (s, 2H), 4.22 (q, J = 7.2 Hz, 2H), 4.98 (dd, J = 14.5 Hz, 5.4 Hz, 1H), 5.78 (s, 1H), 7.24 (s, 1H),

7.28 (d, J = 0.9 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ -0.6, 14.0, 24.1, 29.2, 45.7, 48.8, 49.4, 62.1, 119.4, 122.8, 126.7, 141.9, 148.8, 163.4, 172.4, 190.0; Data of the minor component: ^{1}H NMR ($CDCl_3$) δ 0.17 (s, 9H), 1.29 (t, J = 7.2 Hz, 3H), 1.57 (s, 3H), 2.47–2.60 (m, 1H), 3.01–3.08 (m, 1H), 3.20–3.41 (m, 2H), 4.22 (q, J = 7.2 Hz, 2H), 4.58–4.74 (m, 1H), 5.78 (s, 1H), 7.24 (s, 1H), 7.28 (d, J = 0.9 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ -0.6, 13.9, 22.9, 29.0, 44.2, 47.1, 49.4, 62.0, 119.2, 122.6, 125.7, 141.9, 148.9, 165.0, 172.9, 190.6.

Ethyl 1-methyl-4-oxo-2-(4-trimethylsilylfuran-3-yl)methylcyclohex-2-ene-1-carboxylate (112).[50] To a stirred solution of **111** (9.34 g, 22.60 mmol) in glacial acetic acid (103.49 mL), zinc dust (3.69 g, 56.50 mmol) was added, and stirred continuously under N_2 for 2 h at 20°C. After filtration, acetic acid was evaporated *in vacuo*, the residue was purified by column chromatography on silica gel (250 g, hexane-EtOAc, 9:1) to give **112** (6.57 g, 87%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.16 (s, 9H), 1.27 (t, J = 7.2 Hz, 3H), 1.49 (s, 3H), 1.93–2.01 (m, 1H), 2.38–2.56 (m, 3H), 3.40 (s, 2H), 4.15–4.23 (m, 2H), 5.66 (s, 1H), 7.23 (s, 1H), 7.26 (d, J = 1.2 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ -0.6, 14.1, 22.7, 29.2, 34.2, 34.6, 47.2, 61.5, 119.3, 123.1, 128.0, 141.8, 148.7, 163.8, 173.9, 198.1.

Ethyl 1-methyl-4-hydroxy-2-(4-trimethylsilylfuran-3-yl)methylcyclohex-2-ene-1-carboxylate (113).[50] To a solution of **112** (6.57 g, 19.64 mmol) in absolute ethanol (57 mL) under N_2 at 0°C, $CeCl_3$ (7.26 g, 29.46 mmol) and $NaBH_4$ (1.49 g, 39.28 mmol) were added accordingly. The reaction mixture was then stirred at 20°C, kept stirring for another 2 hr, and quenched with saturated aqueous NH_4Cl solution (250 mL). The aqueous portion was extracted with EtOAc (3 x 300 mL). The combined

organic portion was washed with brine (500 mL), dried over $MgSO_4$, and concentrated under reduced pressure. The residue was then purified by column chromatography on silica gel (150 g, hexane-EtOAc, 2:1) to yield **113** (5.65 g, 86%) as a colorless oil; Compound **113** showed very complex ^1H NMR and ^{13}C NMR spectra due to the presence of a pair of diastereomers; Data of the major component: ^1H NMR ($CDCl_3$) δ 0.19 (s, 9H), 1.22–1.29 (m, 3H), 1.32 (s, 3H), 1.44–1.80 (m, 3H), 1.80–2.01 (m, 1H), 2.12–2.27 (m, 1H), 3.15 (s, 2H), 4.06–4.26 (m, 3H), 5.37 (t, J = 1.5 Hz, 1H), 7.24 (d, J = 0.3 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ -0.5, 14.2, 23.3, 28.2, 28.4, 32.5, 46.7, 60.4, 60.9, 65.8, 119.6, 125.3, 128.4, 141.7, 148.3, 176.1; Data of the minor component: ^1H NMR ($CDCl_3$) δ 0.19 (s, 9H), 1.22–1.29 (m, 3H), 1.39 (s, 3H), 1.44–1.80 (m, 3H), 1.80–2.01 (m, 1H), 2.01–2.12 (m, 1H), 3.15 (s, 2H), 4.06–4.26 (m, 3H), 5.35 (t, J = 1.5 Hz, 1H), 7.23 (d, J = 0.3 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ -0.5, 14.2, 23.2, 28.2, 28.7, 32.2, 46.4, 60.4, 60.8, 65.8, 119.6, 125.2, 128.2, 141.7, 148.3, 176.0.

6,7,8,8a-Tetrahydro-6-hydroxy-8a-methyl-3-(trimethylsilyl)naphtho[2,3-*b*]furan-9(4*H*)-one (114 and 115).[50] To a solution of **113** (5.65 g, 16.80 mmol) in MeOH (126 mL), an aqueous solution of 2 M NaOH (42 mL) was added slowly under N_2. The reaction mixture was then refluxed for 24 hr, diluted with water (50 mL), and washed with CH_2Cl_2 (100 mL). The aqueous layer was acidified with 3 N HCl to *p*H 4, and extracted with CH_2Cl_2 (3 x 250 mL). The combined organic layer was dried over $MgSO_4$, concentrated and dried under reduced pressure for 10 hr. The residue was dissolved in anhydrous CH_2Cl_2 (84 mL), trifluoroacetic anhydride (7.12 mL, 50.39 mmol) was added slowly. After stirring under N_2 at 20°C for 10 hr, saturated $NaHCO_3$ solution (200 mL) was used to quench the reaction mixture. The aqueous layer was extracted with Et_2O (3 x 250 mL). The combined organic layer was then washed with

brine (500 mL), and dried over $MgSO_4$. After removal of solvent under reduced pressure, the residue was dried *in vacuo* for 1 hr, and then redissolved in MeOH (50 mL) and saturated $NaHCO_3$ solution (5 mL). After stirring under N_2 at 20°C for 1.5 hr, the reaction mixture was diluted with water (100 mL) and extracted with Et_2O (3 x 200 mL). The combined organic layer was then dried over $MgSO_4$, concentrated under reduced pressure, and subsequently purified by column chromatography on silica gel (100 g, hexane-EtOAc, 3:1) to produce **114** (0.83 g, 17%) and **115** (1.47 g, 31%) as a colorless oil; NMR data of **114**: ^{1}H NMR ($CDCl_3$) δ 0.28 (s, 9H), 1.27 (s, 3H), 1.49–1.67 (m, 3H), 1.87–1.94 (m, 1H), 2.36–2.44 (ddd, J = 13.5 Hz, 11.7 Hz, 2.4 Hz, 1H), 3.24 (d, J = 18.0 Hz, 1H), 3.68 (dt, J = 18.0 Hz, 2.1 Hz, 1H), 4.20–4.21 (m, 1H), 5.74 (t, J = 2.4 Hz, 1 H), 7.43 (s, 1H); ^{13}C NMR ($CDCl_3$) δ -0.9, 24.1, 26.3, 29.3, 30.8, 47.7, 65.4, 119.9, 128.1, 140.4, 140.6, 147.1, 152.3, 189.1; NMR data of **115**: ^{1}H NMR ($CDCl_3$) δ 0.27 (s, 9H), 1.33 (s, 3H), 1.55-1.60 (m, 1H), 1.94–2.01 (m, 3H), 2.04 (br. s, 1H), 3.22 (d, J = 18.3 Hz, 1H), 3.63 (dt, J = 18.3 Hz, 2.1 Hz, 1H), 4.18–4.21 (m, 1H), 5.67 (s, 1H), 7.43 (s, 1H); ^{13}C NMR ($CDCl_3$) δ -0.9, 24.0, 27.9, 29.1, 30.6, 47.5, 66.4, 119.8, 128.6, 139.6, 140.6, 146.9, 152.4, 189.8.

Preparation of Dess-Martin periodinane:[71-73]

1-Hydroxy-1,2-benziodoxol-3(1*H*)-one 1-Oxide. To a stirred mixture of 2-iodobenzoic acid (43.07 g, 0.17 mol) in an aqueous solution of 0.73 M H_2SO_4 (500 mL) was added potassium bromate (38.49 g, 0.23 mol) over 30 min at oil bath temperature of 55°C. The reaction mixture was allowed to stir for a further 3.6 hr at 67°C, then cooled with ice water bath 0°C. After filtration, the residue was washed with ice cold (0°C) water (700 mL) and absolute ethanol (2 x 50 mL) to provide 1-hydroxy-1,2-benziodoxol-3(1*H*)-one 1-oxide (39.39 g, 81%); m.p. 233-234°C [lit.[71]

m.p. 233-233°C].

1,1,1-Triacetoxy-1,1-dihydro-1,2-benziodoxol-3(1*H*)-one. A mixture of 1-hydroxy-1,2-benziodoxol-3(1*H*)-one 1-oxide (29.34 g, 104.83 mmol), *p*-toluenesulfonic acid monohydrate (0.56 g, 2.93 mmol), and acetic anhydride (120 mL) was heated while stirring at oil bath temperature of 80°C for 2 hr. The reaction mixture was subsequently cooled with ice water bath 0°C. After filtration, the residue was washed with anhydrous Et_2O (4 x 25 mL) to produce the Dess-Martin periodinane (38.67 g, 87%) as white crystalline solids; m.p. 132-135°C [lit.[71] m.p. 134°C].

7,8-Dihydro-8a-methyl-3-(trimethylsilyl)naphtho[2,3-*b*]furan-6(4*H*),9(8a*H*)-dione (116).[50] A solution of **114** and **115** (2.43 g, 8.33 mmol), anhydrous CH_2Cl_2 (500 mL), and Dess-Martin periodinane (5.30 g, 12.50 mmol) was stirred under N_2 at 20°C for 4 hr, and then quenched with saturated $NaHCO_3$ solution (300 mL). The aqueous layer was extracted with Et_2O (3 x 350 mL). The combined organic layer was dried over $MgSO_4$ and concentrated under reduced pressure. The residue was column chromatographed on silica gel (95 g, hexane-EtOAc, 4:1) to give **116** (1.97 g, 82%) as a colorless oil, which consists of a $\Delta^{1,10}$ isomer in the ratio of 4:1; Data of the major component: ^{1}H NMR ($CDCl_3$) δ 0.29 (s, 9H), 1.49 (s, 3H), 2.26–2.40 (m, 3H), 2.48–2.53 (m, 1H), 3.48 (d, J = 19.5 Hz, 1H), 3.90 (dd, J = 19.5 Hz, 2.1 Hz, 1H), 5.96 (d, J = 1.8 Hz, 1H), 7.52 (s, 1H); Compound **116** showed very complex ^{13}C NMR spectra due to the presence of a pair of diastereomers .

4,5,7,8-Tetrahydro-8a-methyl-3-(trimethylsilyl)naphtho[2,3-*b*]furan-6(4*H*),10(8a*H*)-dione (117). A solution of **116** (1.97 g, 6.82 mmol) in MeOH (170

mL) was hydrogenated from a hydrogen balloon over platinum (IV) oxide (0.17 g, 0.68 mmol). After stirring for 4.5 hr, the reaction mixture was filtered, washed with EtOAc (30 mL) and hexane (30 mL). Upon removal of solvent under reduced pressure, the residue was purified by column chromatography on silica gel (37 g, hexane-EtOAc, 3:1) to afford **117** (1.16 g, 59%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.22 (s, 9H), 1.31 (s, 3H), 1.50 (td, J = 13.3 Hz, 5.2 Hz, 1H), 2.22–2.56 (m, 6H), 2.63 (dt, J = 13.5 Hz, 4.5 Hz, 1H), 3.13 (dd, J = 17.3 Hz, 4.5 Hz, 1H), 7.46 (s, 1H); ^{13}C NMR ($CDCl_3$) δ -1.0, 23.4, 27.1, 32.8, 38.6, 43.8, 44.7, 46.7, 121.1, 139.5, 146.2, 152.8, 188.6, 210.3; MS (FAB) *m/z* 291 $[M + H]^+$; HRMS (FAB) $[M + H]^+$ Calcd for $C_{16}H_{23}O_3Si$: 291.1411. Found: 291.1423; Anal. Calcd for $C_{16}H_{22}O_3Si$: C, 66.17; H, 7.63. Found: C, 66.15; H, 7.68.

4,5,7,8-Tetrahydro-8a-methyl-6,6-(1',3'-dioxolan-2'-yl)-3-(trimethylsilyl)naphtho[2,3-*b*]furan-9-one (118). A solution of **117** (0.81 g, 2.79 mmol), anhydrous benzene (159 mL), ethylene glycol (3.12 mL, 55 mmol), and *p*-toluenesulfonic acid monohydrate (0.28 g, 1.39 mmol) was refluxed for 15 hr with a Dean-Stark apparatus. After cooling to room temperature, the reaction mixture was diluted with EtOAc (350 mL), then washed consecutively with saturated $NaHCO_3$ solution (350 mL), water (350 mL), and brine (350 mL). The organic solution was then dried over $MgSO_4$. After removal of solvent under reduced pressure, the residue was purified by column chromatography on silica gel (26 g, hexane-EtOAc, 5:1) to furnish **118** (0.77 g, 83%) as colorless crystals; m.p. 162-164°C; ^{1}H NMR ($CDCl_3$) δ 0.18 (d, J = 2.3 Hz, 9H), 1.16 (d, J = 2.5 Hz, 3H), 1.25–1.72 (m, 6H), 2.23–2.45(m, 2H), 3.03–3.18 (m, 1H), 3.79–3.91 (m, 4H), 7.37 (d, J = 2.1 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ -1.0, 24.5, 26.9, 30.9, 32.0, 37.8, 42.1, 46.8, 64.1, 64.2, 108.8, 120.8, 139.7,

146,5, 152.1, 189.7; Anal. Calcd for $C_{18}H_{26}O_4Si$: C, 64.64; H, 7.83. Found: C, 64.74; H, 7.99.

4,5,7,8-Tetrahydro-8a-methyl-6,6-(1',3'-dioxolan-2'-yl)-3-(trimethylsilyl)naphtho(2,3-*b*)furan (121). A solution of **118** (770 mg, 2.31 mmol) in anhydrous THF (60 mL) was added dropwise to an ice cooled (0°C) solution of $LiAlH_4$ (96 mg, 2.31 mmol) in anhydrous THF (200 mL) under N_2. After stirring for 1 hr at 0°C, the reaction mixture was quenched with saturated aqueous NH_4Cl solution (150 mL), filtered through a bed of fuller's earth, and rinsed with EtOAc (50 mL). The aqueous layer was extracted with EtOAc (3 x 200 mL). The combined organic layer was then washed consecutively with water (300 mL), brine (300 mL), and dried over $MgSO_4$. Upon removal of solvent under reduced pressure, the residue was dissolved in anhydrous THF (19 mL) at 0°C. Carbon disulfide (0.74 mL, 12.23 mmol), iodomethane (0.75 mL, 12.00 mmol), and sodium hydride (60% dispersion in mineral oil)(0.14 g, 3.46 mmol) were subsequently added. The mixture was stirred under N_2 for 4.5 hr at 0°C, the reaction mixture was then quenched with water (20 mL). The aqueous layer was extracted with Et_2O (3 x 50 mL). The combined organic layer was washed with brine (20 mL) and dried with $MgSO_4$. After removal of the solvent under reduced pressure, the residue was dissolved in anhydrous toluene (3 mL) and added dropwise under N_2 over 30 min into a hot (110°C) solution of tributyltin hydride (6.21 mL, 23.08 mmol), anhydrous toluene (4 mL), and a catalytic amount of AIBN (3.79 mg, 0.02 mmol). After refluxing for 72 hr, the reaction mixture was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (20 g, hexane-EtOAc, 5:1) to provide **121** (0.16 g, 22%) as a colorless oil; ^1H NMR ($CDCl_3$) δ 0.19 (s, 9H), 0.98 (s, 3H), 1.36–1.92 (m, 7H), 2.09 (t, J = 14.4 Hz,

2H), 2.70–2.89 (m, 2H), 3.87–4.01 (m, 4H), 7.14 (s, 1H); ^{13}C NMR ($CDCl_3$) δ -0.7, 26.8, 27.4, 28.2, 31.3, 33.4, 36.6, 37.7, 38.5, 64.2, 64.2, 109.5, 116.6, 118.7, 145.7, 149.1; MS (EI) *m/z* 320 $[M]^+$; HRMS (EI) $[M]^+$ Calcd for $C_{18}H_{28}O_3Si$: 320.1803. Found: 320.1791.

Ethyl 5-bromo-4-(1',3'-dioxolan-2'-yl)-1-methyl-2-[4-methylfuran-3-yl]methylcyclohex-2-ene-1-carboxylate (125). A solution of **124** (13.34 g, 41.22 mmol) in THF (20 mL) was added to a mixture of **89** (48.61 g, 123.66 mmol), $Pd(PPh_3)_4$ (2.38 g, 2.06 mmol) in THF (260 mL) and an aqueous solution of 2 M K_3PO_4 solution (500 mL), the mixture was then refluxed under N_2 over 21 hr. After filtration, THF was evaporated under reduced pressure. The aqueous residue was extracted with Et_2O (4 x 700 mL). The combined organic extract was washed with brine (700 mL), and dried over $MgSO_4$. After removal of solvent under reduced pressure, the residue was column chromatographed on silica gel (420 g, hexane-EtOAc, 9:1) to afford **125** (29.44 g, 60%) as a pale yellow oil, which consisted of a pair of diastereomers in the ratio of 7:3; NMR data of the major component: ^{1}H NMR ($CDCl_3$) δ 1.26 (t, J = 7.1 Hz, 3H), 1.38 (s, 3H), 1.86 (s, 3H), 2.33 (t, J = 13.7 Hz, 1H) 2.40 (s, 1H), 2.55 (dd, J = 13.6 Hz, 3.7 Hz, 1H), 3.00 (d, J = 17.1 Hz, 1H), 3.88–4.02 (m, 2H), 4.04–4.23 (m, 4H), 4.63 (dd, J = 13.7 Hz, 3.7 Hz, 1H), 5.22 (t, J = 1.5 Hz, 1H), 7.16 (s, 2H); ^{13}C NMR ($CDCl_3$) δ 7.8, 14.1, 23.9, 25.9, 43.6, 48.7, 52.6, 61.4, 65.9, 66.4, 104.5, 116.4, 120.9, 125.5, 139.7, 140.9, 141.3, 173.8; NMR data of the minor component: ^{1}H NMR ($CDCl_3$) δ 1.34 (t, J = 7.1 Hz, 3H), 1.44 (s, 3H), 1.86 (s, 3H), 2.13 (s, 1H), 2.22 (dd, J = 13.0 Hz, 3.5 Hz, 1H), 2.89 (t, J = 13.3 Hz, 1H), 3.15(dd, J = 17.3 Hz, 1.7 Hz, 1H), 4.04–4.23 (m, 4H), 4.23–4.33 (m, 2H), 4.40 (dd, J = 13.6 Hz, 3.5 Hz, 1H), 5.16 (t, J = 1.5 Hz, 1H), 7.16 (s, 2H); ^{13}C NMR ($CDCl_3$) δ 7.8,

13.9, 21.3, 25.6, 42.9, 49.4, 52.0, 61.4, 65.8, 66.5, 104.5, 116.4, 120.2, 124.4, 139.6, 140.8, 142.1, 173.8; MS (EI) *m/z* 398 $[M]^+$; HRMS (FAB) $[M + H]^+$ Calcd for $C_{18}H_{24}O_5Br$: 399.0802, 401.0782. Found: 399.0800, 401.0787; Anal. Calcd for $C_{18}H_{23}O_5Br$: C, 54.15; H, 5.81. Found: C, 54.17; H, 5.98.

Ethyl 5-bromo-1-methyl-4-oxo-2-(4-methylfuran-3-yl)methylcyclohex-2-ene-1-carboxylate (126). A solution of **125** (20.44 g, 51.19 mmol) in 80% acetic acid (255 mL) was warmed under N_2 to an oil bath temperature of 85°C for 6.25 hr. After removal of acetic acid *in vacuo*, the residue was purified by column chromatography on silica gel (600 g, hexane-EtOAc, 9:1) to offer **126** (14.30 g, 79%) as a pale yellow oil, which consisted of a pair of diastereomers in the ratio of 4:1; Data of the major component: ^{1}H NMR ($CDCl_3$) δ 1.28 (t, J = 7.1 Hz, 3H), 1.54 (s, 3H), 1.83 (s, 3H), 2.42 (t, J = 13.6 Hz, 1H), 2.91 (dd, J = 13.6 Hz, 5.3 Hz, 1H), 3.35 (s, 2H), 4.12–4.33 (m, 2H), 4.93 (dd, J = 13.6 Hz, 5.3 Hz, 1H), 5.79 (s, 1H), 7.18 (s, 2H); ^{13}C NMR ($CDCl_3$) δ 7.9, 14.1, 23.8, 27.6, 44.2, 45.7, 48.8, 62.1, 119.5, 124.8, 125.8, 140.3, 141.1, 162.9, 172.4, 190.8; Data of the minor component: ^{1}H NMR ($CDCl_3$) δ 1.28 (t, J = 7.1 Hz, 3H), 1.57 (s, 3H), 1.85 (s, 3H), 2.51 (dd, J = 13.8 Hz, 4.9 Hz, 1H), 3.00 (dd, J = 13.7 Hz, 10.9 Hz, 1H), 3.00 (dd, J = 13.6 Hz, 1.5 Hz, 2H), 4.12–4.33 (m, 2H), 4.66 (dd, J = 10.9 Hz, 4.9 Hz, 1H), 5.75 (s, 1H), 7.18 (s, 2H); ^{13}C NMR ($CDCl_3$) δ 7.8, 14.0, 22.2, 27.2, 45.7, 47.1, 49.4, 62.0, 119.8, 124.8, 125.8, 140.3, 141.1, 164.3, 173.0, 190.0; Anal. Calcd for $C_{16}H_{19}O_4Br$: C, 54.10; H, 5.39. Found: C, 54.10; H, 5.46.

Ethyl 1-methyl–4-oxo-2-(4-methylfuran-3-yl)methylcyclohex-2-ene-1-carboxylate (127). To a stirred solution of **126** (10.96 g, 30.84 mmol) in glacial acetic acid (141 mL), zinc dust (4.03 g, 61.68 mmol) was added, and stirred continuously under N_2 for

3 hr at 28°C. After filtration, acetic acid was removed *in vacuo*, the residue was then purified by column chromatography on silica gel (310 g, hexane-EtOAc, 5:1) to give **127** (5.44 g, 64%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 1.27 (t, J = 7.2 Hz, 3H), 1.53 (d, J = 8.7 Hz, 3H), 1.86 (d, J = 8.1 Hz, 3H), 1.90–2.09 (m, 1H), 2.33–2.64 (m, 3H), 3.32 (d, J = 6.9 Hz, 2H), 4.08–4.31 (m, 2H), 5.68 (d, J = 1.5 Hz, 1H), 7.19 (d, J = 8.1 Hz, 2H); ^{13}C NMR ($CDCl_3$) δ 7.8, 14.1, 22.6, 27.5, 34.2, 34.7, 47.2, 61.5, 119.9, 120.0, 127.2, 140.1, 141.1, 163.2, 174.0, 198.4; Anal. Calcd for $C_{16}H_{20}O_4$: C, 69.55; H, 7.30. Found: C, 69.31; H, 7.41.

Ethyl 1-methyl–4-hydroxy-2-(4-methylfuran-3-yl)methylcyclohex-2-ene-1-carboxylate (128). To a solution of **127** (6.76 g, 24.46 mmol) in absolute ethanol (72 mL) under N_2 at 0°C, $CeCl_3$ (9.04 g, 36.69 mmol) and $NaBH_4$ (1.85 g, 48.92 mmol) were added accordingly. The reaction mixture was then warmed to 28°C, was kept stirring for another 4 hr, and quenched with saturated aqueous NH_4Cl solution (500 mL). The aqueous portion was extracted with EtOAc (3 x 500 mL). The combined organic portion was washed with brine (800 mL), dried over $MgSO_4$, and concentrated under reduced pressure. The residue was finally purified by column chromatography on silica gel (180 g, hexane-EtOAc, 3:1) to yield **128** (4.11 g, 60%) as a colorless oil; Compound **128** showed very complex ^{1}H NMR and ^{13}C NMR spectra due to the presence of a pair of diastereomers; Data of the major component: ^{1}H NMR ($CDCl_3$) δ 1.19–1.27 (m, 3H), 1.31 (s, 3H), 1.45–1.78 (m, 3H), 1.79–1.92 (m, 4H), 2.08–2.20 (m, 1H), 2.92–3.10 (m, 2H), 3.98–4.22 (m, 3H), 5.30–5.39 (m, 1H), 7.13 (s, 2H); ^{13}C NMR ($CDCl_3$) δ 8.0, 14.1, 23.1, 26.3, 28.5, 32.7, 46.4, 60.9, 65.7, 120.4, 121.8, 127.5, 139.6, 139.7, 140.8, 176.1; Data of the minor component: ^{1}H NMR ($CDCl_3$) δ 1.19–1.27 (m, 3H), 1.38 (s, 3H), 1.45–1.78 (m, 3H), 1.79–1.92

(m, 4H), 1.95–2.06 (m, 1H), 2.92–3.10 (m, 2H), 3.98–4.22 (m, 3H), 5.30–5.39 (m, 1H), 7.13 (s, 2H); ^{13}C NMR ($CDCl_3$) δ 8.0, 14.1, 22.9, 26.3, 28.3, 32.2, 46.6, 60.8, 65.6, 120.4, 121.8, 127.1, 139.6, 139.7, 140.6, 176.1; Anal. Calcd for $C_{16}H_{22}O_4$: C, 69.04; H, 7.97. Found: C, 69.04; H, 7.91.

6,7,8,8a-Tetrahydro-6-hydroxy-3,8a-dimethylnaphtho[2,3-*b*]furan-9(4*H*)-one (129 and 130). To a solution of **128** (4.31 g, 15.49 mmol) in MeOH (116 mL), an aqueous solution of 2 M NaOH (39 mL) was added slowly under N_2. The reaction mixture was then refluxed for 24 hr, diluted with water (50 mL), and washed with CH_2Cl_2 (100 mL). The aqueous layer was acidified with 3 N HCl solution to *p*H 4, and extracted with CH_2Cl_2 (3 x 200 mL). The combined organic layer was dried over $MgSO_4$, concentrated and dried under reduced pressure for 10 hr. The residue was dissolved in anhydrous CH_2Cl_2 (77 mL), trifluoroacetic anhydride (13.25 mL, 92.94 mmol) was added slowly. After stirring under N_2 at 27°C for 10 hr, saturated $NaHCO_3$ solution (400 mL) was used to quench the reaction mixture. The aqueous layer was extracted with Et_2O (3 x 500 mL), the combined organic layer was then washed with brine (800 mL), and dried over $MgSO_4$. After removal of solvent under reduced pressure, the residue was dried under reduced pressure for 2 hr, and then redissolved in MeOH (46 mL) and saturated $NaHCO_3$ solution (10 mL). After stirring under N_2 at 27°C for 2.5 hr, the reaction mixture was diluted with water (50 mL) and extracted with Et_2O (3 x 100 mL). The combined organic layer was then dried over $MgSO_4$, concentrated under reduced pressure, and subsequently purified by column chromatography on silica gel (130 g, hexane-EtOAc, 3:1) to produce **129** (0.50 g, 14%) and **130** (0.27 g, 8%) as a colorless oil; NMR data of **129**: ^{1}H NMR ($CDCl_3$) δ 1.25 (s, 3H), 1.43–1.66 (m, 2H), 1.75–1.96 (m, 2H), 2.00 (s, 3H), 2.38 (ddd, J = 13.9

Hz, 10.0 Hz, 2.2 Hz, 1H), 3.15 (d, J = 18.2 Hz, 1H), 3.55 (dt, J = 18.2 Hz, 2.2 Hz, 1H), 4.10–4.26 (m, 1H), 5.73 (t, J = 2.4 Hz, 1 H), 7.36 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 7.7, 24.1, 26.3, 28.4, 29.2, 47.6, 65.4, 120.2, 128.1, 137.0, 140.1, 145.0, 146.1, 189.0; NMR data of **130**: ^{1}H NMR ($CDCl_3$) δ 1.29 (s, 3H), 1.44–1.71 (m, 1H), 1.86–1.95 (m, 3H), 1.98 (d, J = 0.8 Hz, 3H), 2.12–2.40 (m, 1H), 3.13 (d, J = 18.5 Hz, 1H), 3.52 (dt, J = 18.5 Hz, 2.1 Hz, 1H), 4.09–4.27 (m, 1H), 5.66 (s, 1H), 7.35 (d, J = 0.8 Hz, 1 H); ^{13}C NMR ($CDCl_3$) δ 7.6, 22.6, 24.0, 28.1, 28.9, 47.3, 66.3, 120.1, 128.6, 137.0, 139.1, 145.1, 145.8, 189.6; MS (EI) *m/z* 232 $[M]^+$; HRMS (FAB) $[M + H]^+$ Calcd for $C_{14}H_{17}O_3$: 233.1173. Found: 233.1184.

7,8-Dihydro-3,8a-dimethylnaphtho[2,3-*b*]furan-6(4*H*),9(8a*H*)-dione (131). A solution of **129** and **130** (0.27 g, 1.14 mmol), anhydrous CH_2Cl_2 (90 mL), and Dess-Martin periodinane (0.73 g, 1.72 mmol) was stirred under N_2 at 27°C for 3 hr, and then quenched with saturated $NaHCO_3$ solution (100 mL). The aqueous layer was extracted with EtOAc (3 x 100 mL). The combined organic layer was dried over $MgSO_4$, and concentrated under reduced pressure. The residue was column chromatographed on silica gel (7 g, hexane-EtOAc, 2:1) to give **131** (0.19 g, 73%) as a colorless oil, which consists of a $\triangle^{1,10}$ isomer in the ratio of 4:1; Data of the major component: ^{1}H NMR ($CDCl_3$) δ 1.48 (d, J = 1.6 Hz, 3H), 2.05 (d, J = 1.1 Hz, 3H), 2.15–2.46 (m, 3H), 2.47–2.54 (m, 1H), 3.43 (d, J = 19.6 Hz, 1H), 3.79 (dd, J = 19.6 Hz, 1.9 Hz, 1H), 5.97 (d, J = 1.8 Hz, 1H), 7.47 (d, J = 1.1 Hz, 1H); Compound **131** shows very complex ^{13}C NMR spectra due to the presence of a pair of diastereomers (see Appendix). MS (EI) *m/z* 230 $[M]^+$; HRMS (FAB) $[M + H]^+$ Calcd for $C_{14}H_{15}O_3$: 231.1016. Found: 231.1012.

4,5,7,8-Tetrahydro-3,8a-dimethylnaphtho[2,3-*b*]furan-6(4*H*),10(8a*H*)-dione (132). A solution of **131** (55 mg, 0.24 mmol) in MeOH (8 mL) was hydrogenated from a hydrogen balloon over platinum (IV) oxide (11 mg, 0.02 mmol). After stirring for 4 hr, the reaction mixture was filtered, washed with EtOAc (10 mL) and hexane (10 mL). Upon removal of solvent under reduced pressure, the residue was purified by column chromatography on silica gel (5 g, hexane-EtOAc, 2:1) gave **132** (29 mg, 52%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 1.32 (s, 3H), 1.51 (td, J = 13.4 Hz, 5.1 Hz, 1H), 1.99 (s, 3H), 2.23–2.59 (m, 6H), 2.66 (dt, J = 13.6 Hz, 5.4 Hz, 1H), 3.04 (dd, J = 17.6 Hz, 5.0 Hz, 1H), 7.43 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 7.7, 23.6, 24.8, 33.0, 38.7, 44.0, 44.5, 46.8, 121.4, 135.7, 145.3, 145.6, 188.5, 210.5; MS (EI) *m/z* 232 $[M]^+$; HRMS (FAB) $[M + H]^+$ Calcd for $C_{14}H_{17}O_3$: 233.1173. Found: 233.1162.

4,5,7,8-Tetrahydro-3,8a-dimethyl-6,6-(1',3'-dioxolan-2'-yl)naphtho[2,3-*b*]furan-9-one (133). A solution of **132** (29 mg, 0.12 mmol), anhydrous benzene (7 mL), ethylene glycol (0.14 mL, 2.48 mmol), and *p*-toluenesulfonic acid monohydrate (12 mg, 0.06 mmol) was refluxed for 24 hr with a Dean-Stark apparatus. After cooling to room temperature, the reaction mixture was diluted with EtOAc (50 mL), then washed consecutively with saturated $NaHCO_3$ solution (50 mL), water (50 mL), and brine (50 mL). The organic solution was then dried over $MgSO_4$. After removal of solvent under reduced pressure, the residue was purified by column chromatography on silica gel (5 g, hexane-EtOAc, 2:1) to afford **133** (21 mg, 60%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 1.20 (s, 3H), 1.32–1.77 (m, 6H), 1.96 (d, J = 1.0 Hz, 3H), 2.27–2.48 (m, 2H), 3.03 (dd, J = 17.6 Hz, 5.4 Hz, 1H), 3.85–3.96 (m, 4H), 7.36 (d, J = 1.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 7.7, 24.5, 24.7, 31.0, 32.0, 38.1, 41.9, 46.9, 64.2, 64.3, 108.9, 121.1, 127.9, 136.0, 145.0, 189.6; Anal. Calcd for $C_{16}H_{20}O_4$: C, 69.55; H, 7.30. Found:

C, 69.34; H, 7.01.

4,5,7,8-Tetrahydro-3,8a-dimethyl-6,6-(1',3'-dioxolan-2'-yl)naphtho(2,3-*b*)furan (136). A solution of **133** (30 mg, 0.11 mmol) in anhydrous THF (12 mL) was added dropwise to an ice cooled (0°C) solution of $LiAlH_4$ (5 mg, 0.13 mmol) in anhydrous THF (5 mL) under N_2. After stirring for 1 hr at 0°C, the reaction mixture was quenched with saturated aqueous NH_4Cl solution (5 mL), filtered through a bed of fuller's earth, and rinsed with EtOAc (5 mL). The aqueous layer was extracted with EtOAc (3 x 15 mL). The combined organic layer was then washed consecutively with water (10 mL), brine (10 mL), and dried over $MgSO_4$. Upon removal of solvent under reduced pressure, the residue was dissolved in anhydrous THF (19 mL) at 0°C. Carbon disulfide (0.05 mL, 0.83 mmol), iodomethane (0.05 mL, 0.80 mmol), and sodium hydride (60% dispersion in mineral oil) (40 mg, 1.00 mmol) were subsequently added. The mixture was stirred under N_2 for 5 hr at 0°C, the reaction mixture was quenched with water (10 mL). The aqueous layer was extracted with Et_2O (3 x 15 mL). The combined organic layer was washed with brine, dried with $MgSO_4$ and concentrated under reduced pressure, the residue was dissolved in anhydrous toluene (7 mL) and added dropwise under N_2 over 30 min into a hot (110°C) solution of tributyltin hydride (0.28 mL, 1.04 mmol), anhydrous toluene (4 mL), and a catalytic amount of AIBN (1 mg, 0.006 mmol). After refluxing for 72 hr, the reaction mixture was concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (5 g, hexane-EtOAc, 10:1) to yield **136** (14 mg, 47%) as a colorless oil; ^{1}H NMR ($CDCl_3$) δ 0.97 (s, 3H), 1.37–1.92 (m, 10H), 2.01 (dd, J = 16.2 Hz, 3.4 Hz, 2H), 2.55–2.70 (m, 1H), 2.78 (d, J = 16.9 Hz, 1H), 3.84–4.03 (m, 4H), 7.04 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 8.1, 24.3, 27.4, 28.3, 31.3,

33.5, 36.6, 37.7, 38.1, 64.2, 64.2, 109.5, 113.9, 119.7, 137.2, 148.6; MS (EI) *m/z* 262 $[M]^+$ HRMS (EI) $[M]^+$ Calcd for $C_{16}H_{22}O_3$: 262.1564. Found: 262.1552.

4,5,7,8-Tetrahydro-3,8a-dimethylnaphtho[2,3-*b*]furan-6(5*H*)-one (137). A solution of **136** (7 mg, 0.03 mmol) in THF (1 mL), an aqueous solution of 2 N HCl (0.02 mL, 0.04 mmol) was added. The reaction mixture was stirred under N_2 at 27°C for 15.5 hr, diluted with water (5 mL), neutralized with saturated $NaHCO_3$ solution (4 mL) to *p*H 7. After removal of THF under reduced pressure, the aqueous layer was extracted with Et_2O (3 x 15 mL). The combined organic layer was then washed with brine (30 mL), dried over $MgSO_4$, and concentrated under reduced pressure. The residue was purified by column chromatography on silica gel (5 g, hexane-EtOAc, 10:1) to give **137** (3 mg, 45%) as a colorless oil; ^1H NMR ($CDCl_3$) δ 1.14 (s, 3H), 1.64–1.78 (m, 1H), 1.85–2.04 (m, 5H), 2.14 (dd, J = 16.3 Hz, 3.5 Hz, 1H), 2.28 (d, J = 8.2 Hz, 2H), 2.36 (dd, J = 16.3 Hz, 6.7 Hz, 2H), 2.43–2.57 (m, 1H), 2.67–2.79 (m, 1H), 2.88 (d, J = 16.8 Hz, 1H), 7.17 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 8.9, 26.6, 26.9, 30.2, 33.5, 36.7, 37.8, 41.2, 43.9, 114.7, 120.5, 138.0, 149.4, 211.7; HRMS (EI) $[M]^+$ Calcd for $C_{14}H_{18}O_2$: 218.1302. Found: 218.1310.

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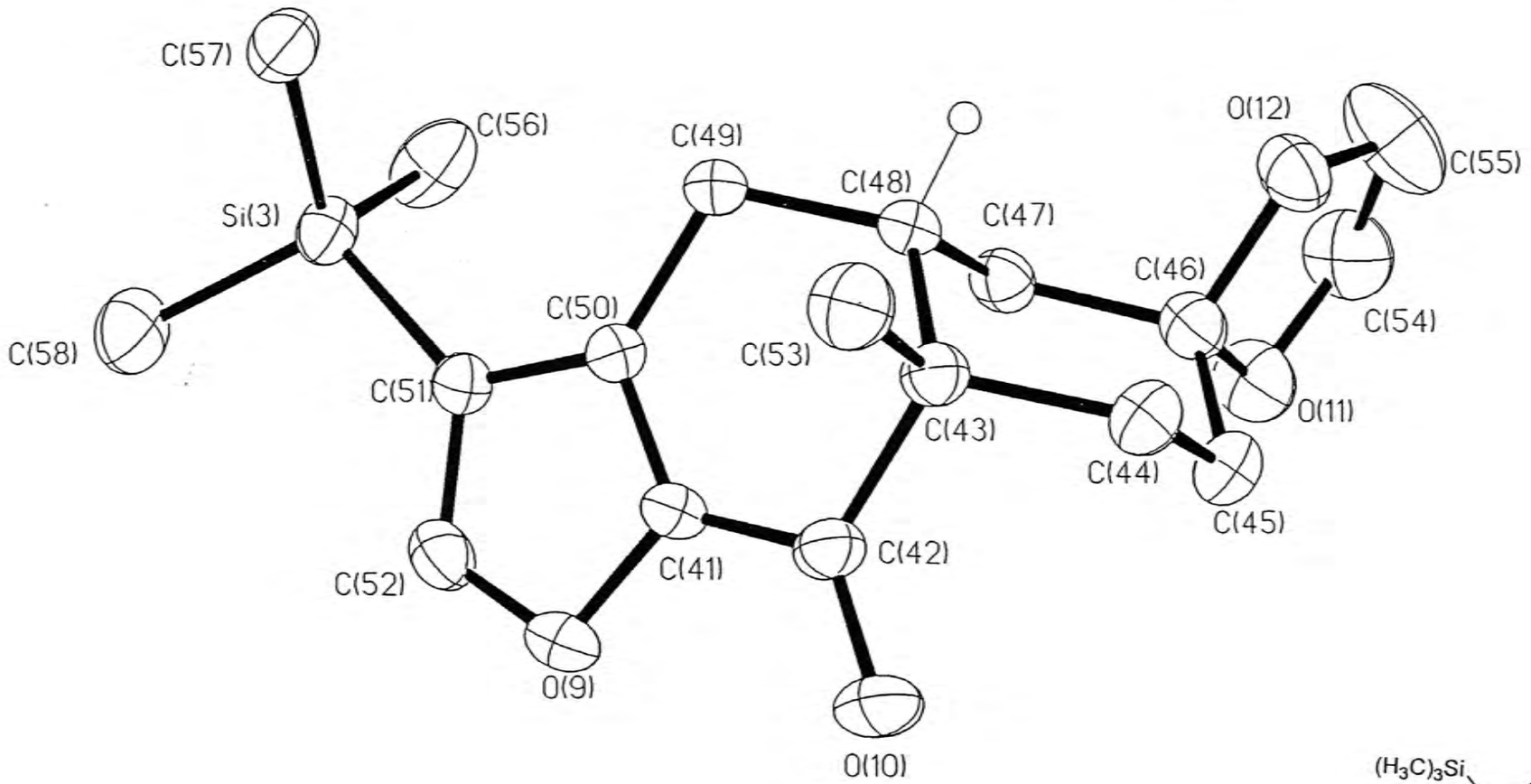
APPENDIX


C(57)
C(56)
Si(3)
C(58)
C(49)
C(48)
C(47)
O(12)
C(55)
C(46)
C(54)
C(50)
C(53)
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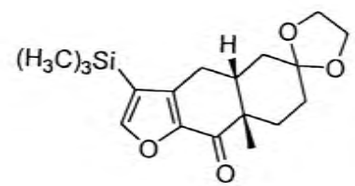
C(52)
C(41)
C(42)
O(9)
O(10)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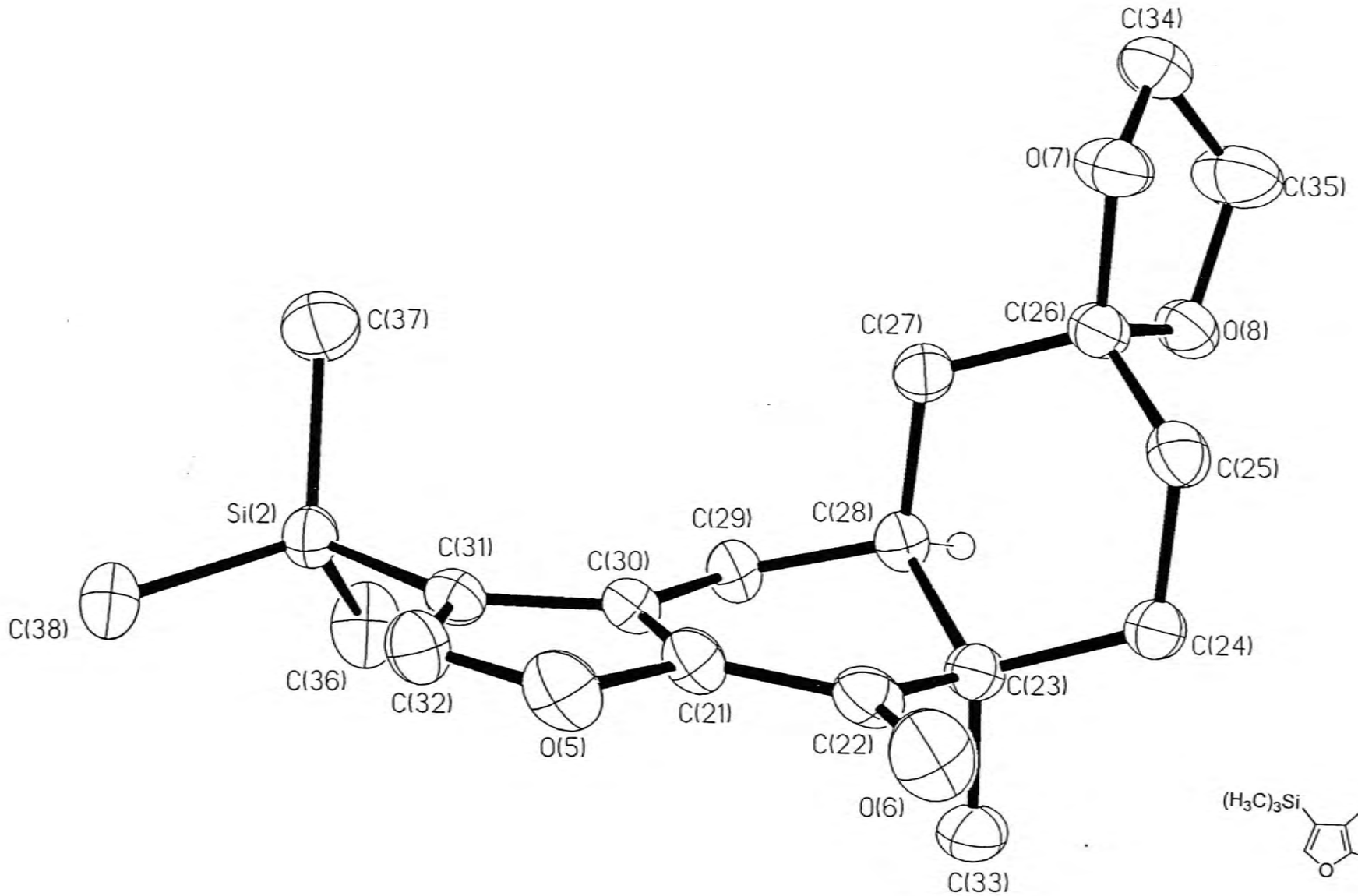
O
O
O
O

(±)-**118**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C(37)
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C(26)
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Si(2)
C(29)
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C(31)
C(30)
C(38)
C(24)
C(36)
C(32)
C(23)
C(21)
O(5)
C(22)
O(6)
C(33)

(H3C)3Si
H
O
O
O
O

(±)-**118**

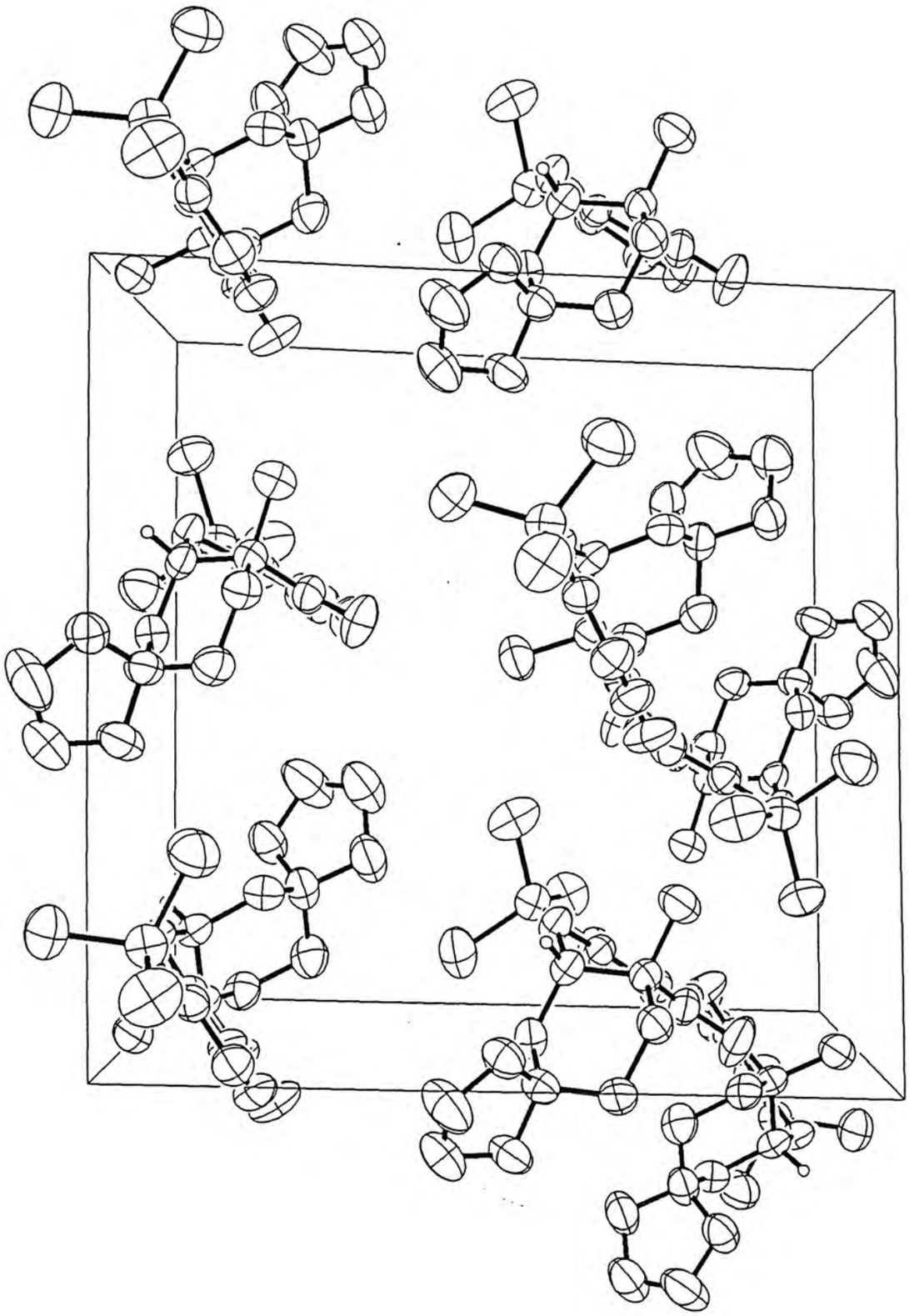


Table 1. Crystal data and structure refinement for TTK003.

Identification code	p-1
Empirical formula	$C_{18}H_{26}O_4Si$
Formula weight	334.48
Temperature	293(2) K
Wavelength	0.71073 Å
Crystal system	Triclinic
Space group	$P\bar{1}$
Unit cell dimensions	a = 14.8187(8) Å alpha = 95.7230(10)° b = 14.8415(9) Å beta = 95.7720(10)° c = 16.8569(10) Å gamma = 91.4710(10)°
Volume, Z	3667.8(4) $Å^3$, 8
Density (calculated)	1.211 Mg/m^3
Absorption coefficient	0.145 mm^{-1}
F(000)	1440
Crystal size	0.40 x 0.40 x 0.35 mm
θ range for data collection	1.22 to 24.00°
Limiting indices	$-16 \le h \le 13$, $-15 \le k \le 16$, $-19 \le l \le 19$
Reflections collected	18882
Independent reflections	11473 (R_{int} = 0.0750)
Completeness to θ = 24.00°	99.6 %
Absorption correction	None
Refinement method	Full-matrix least-squares on F^2
Data / restraints / parameters	11473 / 0 / 830
Goodness-of-fit on F^2	1.035
Final R indices [I>2σ(I)]	R1 = 0.0468, wR2 = 0.1151
R indices (all data)	R1 = 0.0843, wR2 = 0.1343
Extinction coefficient	0.0029(4)
Largest diff. peak and hole	0.284 and -0.301 $eÅ^{-3}$

Table 2. Atomic coordinates [x 10^4] and equivalent isotropic displacement parameters [$Å^2$ x 10^3] for TTK003. U(eq) is defined as one third of the trace of the orthogonalized U_{ij} tensor.

	x	y	z	U(eq)
Si(1)	4407(1)	3108(1)	-435(1)	56(1)
O(1)	3300(1)	5223(1)	799(1)	63(1)
O(2)	2997(1)	5709(1)	2427(1)	82(1)
O(3)	2678(1)	2558(1)	3671(1)	66(1)
O(4)	1358(1)	2758(1)	2893(1)	68(1)
C(1)	3522(2)	4709(2)	1419(2)	50(1)
C(2)	3371(2)	5011(2)	2236(2)	52(1)
C(3)	3769(2)	4390(2)	2848(2)	50(1)
C(4)	3241(2)	4474(2)	3587(2)	58(1)
C(5)	2279(2)	4069(2)	3427(2)	60(1)
C(6)	2275(2)	3092(2)	3083(2)	52(1)
C(7)	2780(2)	2991(2)	2342(1)	50(1)
C(8)	3749(2)	3391(2)	2488(1)	46(1)
C(9)	4226(2)	3268(2)	1717(1)	51(1)
C(10)	3919(2)	3940(2)	1156(1)	45(1)
C(11)	3963(2)	3952(2)	306(2)	49(1)
C(12)	3580(2)	4738(2)	144(2)	62(1)
C(13)	4746(2)	4750(2)	3098(2)	72(1)
C(14)	2055(2)	1870(2)	3783(2)	106(1)
C(15)	1277(2)	1929(2)	3210(2)	83(1)
C(16)	4454(2)	3621(2)	-1384(2)	91(1)
C(17)	3642(2)	2086(2)	-595(2)	99(1)
C(18)	5550(2)	2795(2)	-32(2)	77(1)
Si(2)	5469(1)	1918(1)	4718(1)	56(1)
Si(3)	8939(1)	3231(1)	5222(1)	58(1)
C(41)	7630(2)	3957(2)	3146(2)	51(1)
C(42)	7456(2)	4011(2)	2299(2)	54(1)
C(43)	8178(2)	3567(2)	1809(2)	49(1)
C(44)	8233(2)	4014(2)	1041(2)	57(1)
C(45)	8603(2)	4988(2)	1187(2)	63(1)
C(46)	9517(2)	5041(2)	1657(2)	57(1)
C(47)	9510(2)	4600(2)	2424(2)	53(1)
C(48)	9123(2)	3629(2)	2301(2)	48(1)
C(49)	9113(2)	3229(2)	3103(2)	54(1)
C(50)	8356(2)	3600(2)	3542(2)	47(1)
C(51)	8227(2)	3669(2)	4380(2)	50(1)
C(52)	7420(2)	4084(2)	4400(2)	62(1)
C(53)	7857(2)	2572(2)	1597(2)	70(1)
C(54)	10713(2)	6038(2)	1632(2)	100(1)
C(55)	10855(2)	5228(3)	1128(2)	119(2)
C(56)	9968(2)	3956(2)	5504(2)	103(1)
C(57)	9264(2)	2073(2)	4871(2)	76(1)
C(58)	8271(2)	3193(2)	6096(2)	93(1)
O(9)	7032(1)	4271(1)	3676(1)	63(1)
O(10)	6785(1)	4346(1)	1979(1)	81(1)
O(11)	9825(1)	5970(1)	1828(1)	81(1)
O(12)	10158(1)	4615(1)	1176(1)	71(1)
O(5)	7548(1)	665(1)	5857(1)	66(1)

O(6)	8124(1)	372(1)	7474(1)	83(1)
O(7)	5122(1)	-1052(1)	8067(1)	70(1)
O(8)	5042(1)	269(1)	8871(1)	61(1)
C(21)	7103(2)	949(2)	6512(2)	52(1)
C(22)	7443(2)	786(2)	7311(2)	55(1)
C(23)	6896(2)	1235(2)	7960(2)	49(1)
C(24)	6977(2)	701(2)	8695(2)	56(1)
C(25)	6501(2)	-229(2)	8542(2)	59(1)
C(26)	5518(2)	-160(2)	8244(2)	52(1)
C(27)	5404(2)	363(2)	7522(2)	53(1)
C(28)	5886(2)	1297(2)	7647(1)	46(1)
C(29)	5751(2)	1784(2)	6887(2)	51(1)
C(30)	6356(2)	1404(2)	6283(1)	45(1)
C(31)	6310(2)	1424(2)	5432(2)	48(1)
C(32)	7045(2)	965(2)	5227(2)	62(1)
C(33)	7337(2)	2186(2)	8198(2)	69(1)
C(34)	4256(2)	-1046(2)	8340(2)	80(1)
C(35)	4333(2)	-324(2)	9000(2)	100(1)
C(36)	5213(2)	3072(2)	5152(2)	93(1)
C(37)	4418(2)	1187(2)	4584(2)	94(1)
C(38)	5970(2)	1957(2)	3760(2)	79(1)
Si(4)	9289(1)	8334(1)	-60(1)	58(1)
O(13)	8093(1)	10244(1)	1365(1)	64(1)
O(14)	7968(2)	10590(1)	3044(1)	87(1)
O(15)	6738(1)	7425(2)	3349(1)	81(1)
O(16)	8119(1)	7292(1)	4046(1)	68(1)
C(61)	8488(2)	9743(2)	1934(2)	52(1)
C(62)	8402(2)	9953(2)	2776(2)	56(1)
C(63)	8933(2)	9340(2)	3319(2)	49(1)
C(64)	8481(2)	9273(2)	4082(2)	58(1)
C(65)	7557(2)	8782(2)	3939(2)	66(1)
C(66)	7626(2)	7847(2)	3520(2)	60(1)
C(67)	8081(2)	7867(2)	2761(2)	56(1)
C(68)	9002(2)	8378(2)	2889(1)	47(1)
C(69)	9413(2)	8389(2)	2091(1)	51(1)
C(70)	8935(2)	9046(2)	1593(2)	47(1)
C(71)	8829(2)	9093(2)	740(2)	50(1)
C(72)	8311(2)	9827(2)	659(2)	61(1)
C(73)	9879(2)	9803(2)	3533(2)	66(1)
C(74)	6809(2)	6513(2)	3498(2)	95(1)
C(75)	7591(3)	6507(2)	4104(2)	108(1)
C(76)	9131(2)	8849(2)	-1010(2)	97(1)
C(77)	8710(2)	7209(2)	-154(2)	93(1)
C(78)	10512(2)	8218(2)	244(2)	82(1)

Table 3. Bond lengths [Å] and angles [°] for TTK003.

Si(1)-C(16)	1.845(3)	Si(1)-C(17)	1.851(3)
Si(1)-C(18)	1.849(3)	Si(1)-C(11)	1.861(3)
O(1)-C(12)	1.364(3)	O(1)-C(1)	1.374(3)
O(2)-C(2)	1.217(3)	O(3)-C(14)	1.398(3)
O(3)-C(6)	1.424(3)	O(4)-C(15)	1.397(3)
O(4)-C(6)	1.429(3)	C(1)-C(10)	1.352(3)
C(1)-C(2)	1.448(4)	C(2)-C(3)	1.535(4)
C(3)-C(13)	1.533(3)	C(3)-C(4)	1.533(3)
C(3)-C(8)	1.544(3)	C(4)-C(5)	1.521(3)
C(5)-C(6)	1.506(3)	C(6)-C(7)	1.515(3)
C(7)-C(8)	1.528(3)	C(8)-C(9)	1.537(3)
C(9)-C(10)	1.491(3)	C(10)-C(11)	1.442(3)
C(11)-C(12)	1.351(3)	C(14)-C(15)	1.438(4)
Si(2)-C(38)	1.850(3)	Si(2)-C(37)	1.857(3)
Si(2)-C(36)	1.859(3)	Si(2)-C(31)	1.860(3)
Si(3)-C(56)	1.838(3)	Si(3)-C(57)	1.853(3)
Si(3)-C(58)	1.861(3)	Si(3)-C(51)	1.863(3)
C(41)-C(50)	1.357(3)	C(41)-O(9)	1.377(3)
C(41)-C(42)	1.435(4)	C(42)-O(10)	1.224(3)
C(42)-C(43)	1.539(3)	C(43)-C(44)	1.521(3)
C(43)-C(53)	1.536(3)	C(43)-C(48)	1.548(3)
C(44)-C(45)	1.520(3)	C(45)-C(46)	1.495(4)
C(46)-O(12)	1.429(3)	C(46)-O(11)	1.433(3)
C(46)-C(47)	1.507(4)	C(47)-C(48)	1.524(3)
C(48)-C(49)	1.532(3)	C(49)-C(50)	1.492(3)
C(50)-C(51)	1.438(3)	C(51)-C(52)	1.361(3)
C(52)-O(9)	1.354(3)	C(54)-O(11)	1.392(3)
C(54)-C(55)	1.433(4)	C(55)-O(12)	1.372(3)
O(5)-C(32)	1.355(3)	O(5)-C(21)	1.379(3)
O(6)-C(22)	1.218(3)	O(7)-C(34)	1.406(3)
O(7)-C(26)	1.425(3)	O(8)-C(35)	1.400(3)
O(8)-C(26)	1.435(3)	C(21)-C(30)	1.354(3)
C(21)-C(22)	1.435(4)	C(22)-C(23)	1.535(4)
C(23)-C(24)	1.533(3)	C(23)-C(33)	1.539(3)
C(23)-C(28)	1.544(3)	C(24)-C(25)	1.520(3)
C(25)-C(26)	1.501(3)	C(26)-C(27)	1.505(3)
C(27)-C(28)	1.529(3)	C(28)-C(29)	1.531(3)
C(29)-C(30)	1.501(3)	C(30)-C(31)	1.433(3)
C(31)-C(32)	1.356(3)	C(34)-C(35)	1.459(4)
Si(4)-C(76)	1.839(3)	Si(4)-C(77)	1.843(3)
Si(4)-C(78)	1.851(3)	Si(4)-C(71)	1.862(3)
O(13)-C(72)	1.359(3)	O(13)-C(61)	1.367(3)
O(14)-C(62)	1.231(3)	O(15)-C(74)	1.406(4)
O(15)-C(66)	1.432(3)	O(16)-C(75)	1.403(3)
O(16)-C(66)	1.430(3)	C(61)-C(70)	1.353(3)
C(61)-C(62)	1.440(4)	C(62)-C(63)	1.531(4)
C(63)-C(64)	1.520(3)	C(63)-C(73)	1.538(3)
C(63)-C(68)	1.546(3)	C(64)-C(65)	1.520(3)
C(65)-C(66)	1.502(4)	C(66)-C(67)	1.508(3)
C(67)-C(68)	1.529(3)	C(68)-C(69)	1.533(3)
C(69)-C(70)	1.496(3)	C(70)-C(71)	1.440(3)
C(71)-C(72)	1.358(4)	C(74)-C(75)	1.467(4)

C(16)-Si(1)-C(17)	110.22(16)	C(16)-Si(1)-C(18)	110.86(15)
C(17)-Si(1)-C(18)	109.36(16)	C(16)-Si(1)-C(11)	108.48(14)

C(17)-Si(1)-C(11)	109.18(13)	C(18)-Si(1)-C(11)	108.71(12)
C(12)-O(1)-C(1)	104.48(19)	C(14)-O(3)-C(6)	108.8(2)
C(15)-O(4)-C(6)	107.9(2)	C(10)-C(1)-O(1)	110.9(2)
C(10)-C(1)-C(2)	127.2(2)	O(1)-C(1)-C(2)	121.9(2)
O(2)-C(2)-C(1)	123.5(3)	O(2)-C(2)-C(3)	123.0(2)
C(1)-C(2)-C(3)	113.5(2)	C(13)-C(3)-C(4)	108.7(2)
C(13)-C(3)-C(2)	105.6(2)	C(4)-C(3)-C(2)	109.8(2)
C(13)-C(3)-C(8)	111.1(2)	C(4)-C(3)-C(8)	109.74(19)
C(2)-C(3)-C(8)	111.82(19)	C(5)-C(4)-C(3)	113.5(2)
C(6)-C(5)-C(4)	111.2(2)	O(3)-C(6)-O(4)	106.44(19)
O(3)-C(6)-C(5)	109.8(2)	O(4)-C(6)-C(5)	109.22(19)
O(3)-C(6)-C(7)	110.0(2)	O(4)-C(6)-C(7)	110.3(2)
C(5)-C(6)-C(7)	111.0(2)	C(6)-C(7)-C(8)	113.23(19)
C(7)-C(8)-C(9)	110.83(19)	C(7)-C(8)-C(3)	111.27(18)
C(9)-C(8)-C(3)	112.35(19)	C(10)-C(9)-C(8)	111.08(19)
C(1)-C(10)-C(11)	107.3(2)	C(1)-C(10)-C(9)	121.1(2)
C(11)-C(10)-C(9)	131.5(2)	C(12)-C(11)-C(10)	103.7(2)
C(12)-C(11)-Si(1)	125.9(2)	C(10)-C(11)-Si(1)	130.44(19)
C(11)-C(12)-O(1)	113.6(2)	O(3)-C(14)-C(15)	107.2(3)
O(4)-C(15)-C(14)	107.2(2)	C(38)-Si(2)-C(37)	111.16(15)
C(38)-Si(2)-C(36)	111.17(15)	C(37)-Si(2)-C(36)	109.47(16)
C(38)-Si(2)-C(31)	108.02(13)	C(37)-Si(2)-C(31)	108.23(14)
C(36)-Si(2)-C(31)	108.70(13)	C(56)-Si(3)-C(57)	109.40(15)
C(56)-Si(3)-C(58)	110.02(17)	C(57)-Si(3)-C(58)	109.94(14)
C(56)-Si(3)-C(51)	110.37(14)	C(57)-Si(3)-C(51)	107.58(12)
C(58)-Si(3)-C(51)	109.50(14)	C(50)-C(41)-O(9)	110.4(2)
C(50)-C(41)-C(42)	127.5(2)	O(9)-C(41)-C(42)	122.1(2)
O(10)-C(42)-C(41)	124.2(2)	O(10)-C(42)-C(43)	122.0(2)
C(41)-C(42)-C(43)	113.8(2)	C(44)-C(43)-C(53)	109.3(2)
C(44)-C(43)-C(42)	110.4(2)	C(53)-C(43)-C(42)	105.9(2)
C(44)-C(43)-C(48)	109.59(19)	C(53)-C(43)-C(48)	110.4(2)
C(42)-C(43)-C(48)	111.2(2)	C(45)-C(44)-C(43)	113.3(2)
C(46)-C(45)-C(44)	110.8(2)	O(12)-C(46)-O(11)	105.86(19)
O(12)-C(46)-C(45)	109.3(2)	O(11)-C(46)-C(45)	109.6(2)
O(12)-C(46)-C(47)	109.7(2)	O(11)-C(46)-C(47)	110.1(2)
C(45)-C(46)-C(47)	112.1(2)	C(46)-C(47)-C(48)	113.6(2)
C(47)-C(48)-C(49)	110.9(2)	C(47)-C(48)-C(43)	111.3(2)
C(49)-C(48)-C(43)	112.70(19)	C(50)-C(49)-C(48)	110.3(2)
C(41)-C(50)-C(51)	108.0(2)	C(41)-C(50)-C(49)	120.9(2)
C(51)-C(50)-C(49)	131.1(2)	C(52)-C(51)-C(50)	102.7(2)
C(52)-C(51)-Si(3)	128.2(2)	C(50)-C(51)-Si(3)	128.94(19)
O(9)-C(52)-C(51)	114.4(2)	O(11)-C(54)-C(55)	106.4(3)
O(12)-C(55)-C(54)	108.5(3)	C(52)-O(9)-C(41)	104.45(19)
C(54)-O(11)-C(46)	108.0(2)	C(55)-O(12)-C(46)	108.6(2)
C(32)-O(5)-C(21)	104.53(19)	C(34)-O(7)-C(26)	107.8(2)
C(35)-O(8)-C(26)	107.9(2)	C(30)-C(21)-O(5)	110.5(2)
C(30)-C(21)-C(22)	127.6(2)	O(5)-C(21)-C(22)	121.9(2)
O(6)-C(22)-C(21)	124.1(3)	O(6)-C(22)-C(23)	122.3(3)
C(21)-C(22)-C(23)	113.6(2)	C(22)-C(23)-C(24)	109.9(2)
C(22)-C(23)-C(33)	105.9(2)	C(24)-C(23)-C(33)	108.8(2)
C(22)-C(23)-C(28)	111.6(2)	C(24)-C(23)-C(28)	109.69(19)
C(33)-C(23)-C(28)	110.7(2)	C(25)-C(24)-C(23)	113.3(2)
C(26)-C(25)-C(24)	111.3(2)	O(7)-C(26)-O(8)	105.84(18)
O(7)-C(26)-C(25)	108.7(2)	O(8)-C(26)-C(25)	109.7(2)
O(7)-C(26)-C(27)	111.1(2)	O(8)-C(26)-C(27)	109.7(2)
C(25)-C(26)-C(27)	111.6(2)	C(26)-C(27)-C(28)	113.89(19)
C(27)-C(28)-C(29)	111.04(19)	C(27)-C(28)-C(23)	111.38(19)
C(29)-C(28)-C(23)	112.76(19)	C(30)-C(29)-C(28)	110.22(19)
C(21)-C(30)-C(31)	107.6(2)	C(21)-C(30)-C(29)	120.9(2)

C(31)-C(30)-C(29)	131.5(2)	C(32)-C(31)-C(30)	103.7(2)
C(32)-C(31)-Si(2)	125.1(2)	C(30)-C(31)-Si(2)	131.25(18)
O(5)-C(32)-C(31)	113.8(2)	O(7)-C(34)-C(35)	104.0(2)
O(8)-C(35)-C(34)	107.1(3)	C(76)-Si(4)-C(77)	110.95(16)
C(76)-Si(4)-C(78)	110.16(16)	C(77)-Si(4)-C(78)	109.13(16)
C(76)-Si(4)-C(71)	109.09(14)	C(77)-Si(4)-C(71)	109.85(13)
C(78)-Si(4)-C(71)	107.60(12)	C(72)-O(13)-C(61)	104.51(19)
C(74)-O(15)-C(66)	107.6(2)	C(75)-O(16)-C(66)	109.0(2)
C(70)-C(61)-O(13)	110.9(2)	C(70)-C(61)-C(62)	126.9(2)
O(13)-C(61)-C(62)	122.3(2)	O(14)-C(62)-C(61)	123.4(3)
O(14)-C(62)-C(63)	122.3(2)	C(61)-C(62)-C(63)	114.3(2)
C(64)-C(63)-C(62)	110.5(2)	C(64)-C(63)-C(73)	109.2(2)
C(62)-C(63)-C(73)	105.7(2)	C(64)-C(63)-C(68)	109.1(2)
C(62)-C(63)-C(68)	111.26(19)	C(73)-C(63)-C(68)	110.98(19)
C(65)-C(64)-C(63)	113.3(2)	C(66)-C(65)-C(64)	111.0(2)
O(15)-C(66)-O(16)	105.4(2)	O(15)-C(66)-C(65)	109.6(2)
O(16)-C(66)-C(65)	109.7(2)	O(15)-C(66)-C(67)	110.4(2)
O(16)-C(66)-C(67)	109.7(2)	C(65)-C(66)-C(67)	111.8(2)
C(66)-C(67)-C(68)	113.3(2)	C(67)-C(68)-C(69)	110.3(2)
C(67)-C(68)-C(63)	111.59(19)	C(69)-C(68)-C(63)	112.42(19)
C(70)-C(69)-C(68)	110.05(19)	C(61)-C(70)-C(71)	107.6(2)
C(61)-C(70)-C(69)	121.1(2)	C(71)-C(70)-C(69)	131.3(2)
C(72)-C(71)-C(70)	103.0(2)	C(72)-C(71)-Si(4)	128.4(2)
C(70)-C(71)-Si(4)	128.58(19)	C(71)-C(72)-O(13)	113.9(3)
O(15)-C(74)-C(75)	104.8(3)	O(16)-C(75)-C(74)	106.2(3)

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters [$Å^2$ x 10^3] for TTK003.

The anisotropic displacement factor exponent takes the form:

$-2\pi^2 [(ha^*)^2 U_{11} + ... + 2hka^* b^* U_{12}]$

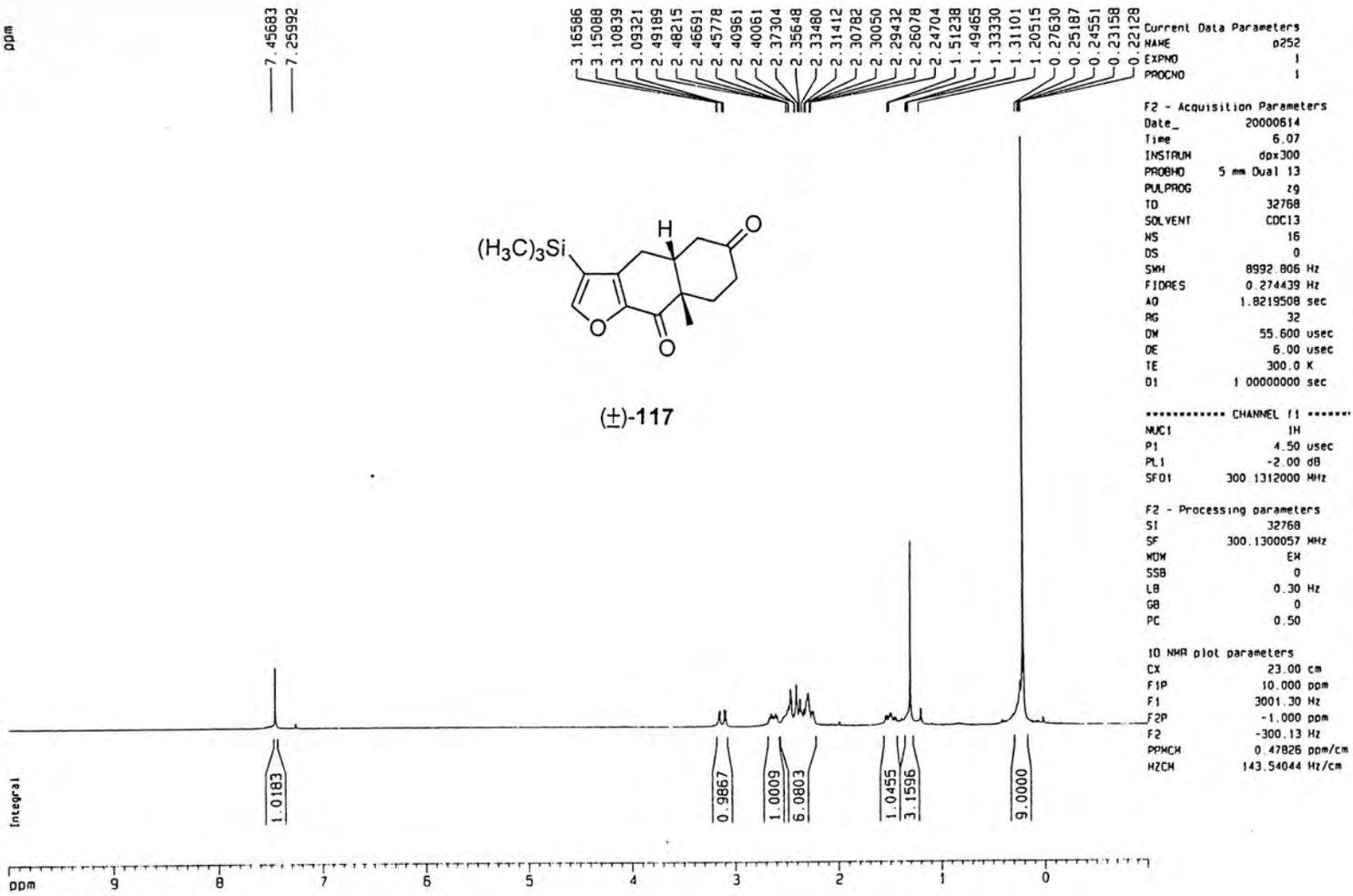
	U11	U22	U33	U23	U13	U12
Si(1)	58(1)	61(1)	50(1)	6(1)	10(1)	3(1)
O(1)	71(1)	51(1)	73(1)	22(1)	11(1)	18(1)
O(2)	110(2)	48(1)	94(2)	7(1)	36(1)	30(1)
O(3)	55(1)	81(1)	66(1)	32(1)	4(1)	5(1)
O(4)	48(1)	74(1)	85(1)	33(1)	-1(1)	-7(1)
C(1)	54(2)	41(1)	57(2)	14(1)	9(1)	8(1)
C(2)	50(2)	38(2)	69(2)	5(1)	14(1)	4(1)
C(3)	45(2)	51(2)	54(2)	1(1)	9(1)	2(1)
C(4)	61(2)	59(2)	52(2)	-3(1)	10(1)	6(1)
C(5)	55(2)	66(2)	61(2)	6(1)	19(1)	8(1)
C(6)	42(2)	61(2)	54(2)	18(1)	4(1)	2(1)
C(7)	60(2)	41(1)	50(2)	7(1)	4(1)	2(1)
C(8)	48(2)	47(2)	46(2)	10(1)	7(1)	13(1)
C(9)	57(2)	46(2)	53(2)	10(1)	13(1)	16(1)
C(10)	43(1)	43(1)	51(2)	10(1)	9(1)	7(1)
C(11)	48(2)	50(2)	51(2)	13(1)	3(1)	3(1)
C(12)	67(2)	65(2)	56(2)	16(2)	9(1)	12(1)
C(13)	52(2)	84(2)	78(2)	-2(2)	3(2)	-10(2)
C(14)	111(3)	90(3)	116(3)	52(2)	-26(2)	-30(2)
C(15)	73(2)	89(2)	92(2)	39(2)	9(2)	-11(2)
C(16)	103(3)	115(3)	58(2)	19(2)	12(2)	18(2)
C(17)	96(3)	80(2)	119(3)	-19(2)	29(2)	-12(2)
C(18)	76(2)	83(2)	74(2)	11(2)	17(2)	20(2)
Si(2)	57(1)	61(1)	51(1)	8(1)	5(1)	4(1)
Si(3)	72(1)	49(1)	52(1)	7(1)	7(1)	2(1)
C(41)	39(1)	56(2)	61(2)	11(1)	13(1)	9(1)
C(42)	42(2)	57(2)	64(2)	13(1)	1(1)	6(1)
C(43)	44(2)	48(2)	54(2)	8(1)	4(1)	3(1)
C(44)	62(2)	55(2)	52(2)	8(1)	-2(1)	2(1)
C(45)	70(2)	57(2)	63(2)	19(1)	6(2)	6(1)
C(46)	62(2)	45(2)	68(2)	6(1)	18(1)	0(1)
C(47)	42(1)	63(2)	55(2)	6(1)	5(1)	-1(1)
C(48)	40(1)	52(2)	54(2)	11(1)	12(1)	11(1)
C(49)	45(2)	65(2)	57(2)	19(1)	11(1)	16(1)
C(50)	43(2)	48(2)	53(2)	12(1)	8(1)	5(1)
C(51)	51(2)	47(2)	55(2)	9(1)	11(1)	3(1)
C(52)	64(2)	64(2)	60(2)	3(2)	22(2)	3(1)
C(53)	73(2)	55(2)	82(2)	6(2)	9(2)	-6(1)
C(54)	81(3)	83(3)	136(3)	16(2)	18(2)	-27(2)
C(55)	86(3)	138(4)	126(3)	-34(3)	45(2)	-52(2)
C(56)	103(3)	85(2)	115(3)	25(2)	-33(2)	-15(2)
C(57)	97(2)	65(2)	70(2)	17(2)	18(2)	18(2)
C(58)	134(3)	89(2)	60(2)	9(2)	29(2)	19(2)
O(9)	48(1)	72(1)	71(1)	7(1)	17(1)	16(1)
O(10)	54(1)	110(2)	81(2)	24(1)	-1(1)	31(1)
O(11)	85(2)	51(1)	107(2)	4(1)	22(1)	-15(1)
O(12)	73(1)	62(1)	82(1)	9(1)	32(1)	-2(1)
O(5)	52(1)	75(1)	77(1)	15(1)	25(1)	21(1)

O(6)	51(1)	107(2)	100(2)	42(1)	12(1)	34(1)
O(7)	72(1)	55(1)	81(1)	1(1)	17(1)	-18(1)
O(8)	67(1)	60(1)	58(1)	6(1)	18(1)	-11(1)
C(21)	44(2)	55(2)	60(2)	15(1)	15(1)	11(1)
C(22)	38(2)	56(2)	75(2)	23(1)	7(1)	5(1)
C(23)	42(1)	49(2)	56(2)	16(1)	-1(1)	1(1)
C(24)	50(2)	57(2)	62(2)	18(1)	-4(1)	-3(1)
C(25)	58(2)	55(2)	64(2)	23(1)	1(1)	0(1)
C(26)	55(2)	47(2)	53(2)	5(1)	10(1)	-7(1)
C(27)	40(1)	66(2)	52(2)	10(1)	3(1)	-1(1)
C(28)	45(1)	50(2)	46(2)	9(1)	8(1)	10(1)
C(29)	45(1)	57(2)	54(2)	15(1)	9(1)	15(1)
C(30)	42(1)	43(1)	52(2)	11(1)	10(1)	4(1)
C(31)	45(2)	47(2)	54(2)	6(1)	12(1)	1(1)
C(32)	64(2)	68(2)	56(2)	8(2)	16(2)	8(1)
C(33)	69(2)	57(2)	80(2)	17(2)	-6(2)	-15(1)
C(34)	77(2)	88(2)	78(2)	13(2)	16(2)	-31(2)
C(35)	92(3)	101(3)	105(3)	-10(2)	39(2)	-37(2)
C(36)	119(3)	79(2)	84(2)	11(2)	15(2)	35(2)
C(37)	63(2)	119(3)	100(3)	17(2)	-2(2)	-9(2)
C(38)	91(2)	94(2)	53(2)	6(2)	8(2)	1(2)
Si(4)	60(1)	64(1)	49(1)	7(1)	6(1)	1(1)
O(13)	72(1)	53(1)	70(1)	17(1)	7(1)	18(1)
O(14)	110(2)	67(1)	85(2)	-1(1)	18(1)	48(1)
O(15)	54(1)	91(2)	96(2)	18(1)	3(1)	-14(1)
O(16)	62(1)	74(1)	70(1)	21(1)	6(1)	-13(1)
C(61)	60(2)	41(2)	57(2)	13(1)	5(1)	13(1)
C(62)	62(2)	42(2)	67(2)	4(1)	12(1)	14(1)
C(63)	52(2)	43(1)	53(2)	-2(1)	10(1)	7(1)
C(64)	60(2)	59(2)	55(2)	-5(1)	12(1)	8(1)
C(65)	60(2)	79(2)	62(2)	1(2)	20(1)	5(1)
C(66)	47(2)	70(2)	63(2)	13(2)	5(1)	-6(1)
C(67)	67(2)	46(2)	54(2)	4(1)	7(1)	1(1)
C(68)	53(2)	43(1)	47(2)	7(1)	10(1)	12(1)
C(69)	62(2)	44(1)	50(2)	8(1)	15(1)	14(1)
C(70)	48(2)	40(1)	54(2)	9(1)	9(1)	3(1)
C(71)	49(2)	50(2)	52(2)	14(1)	5(1)	-1(1)
C(72)	64(2)	64(2)	58(2)	20(2)	-2(1)	2(1)
C(73)	65(2)	59(2)	72(2)	5(2)	9(2)	-3(1)
C(74)	79(2)	98(3)	108(3)	20(2)	7(2)	-30(2)
C(75)	112(3)	91(3)	119(3)	36(2)	-15(3)	-44(2)
C(76)	127(3)	111(3)	53(2)	12(2)	4(2)	23(2)
C(77)	96(3)	75(2)	103(3)	-12(2)	15(2)	-9(2)
C(78)	67(2)	104(3)	78(2)	13(2)	17(2)	12(2)

Table 5. Hydrogen coordinates (x 10^4) and isotropic displacement parameters ($Å^2$ x 10^3) for TTK003.

	x	y	z	U(eq)
H(4A)	3568	4173	4008	69
H(4B)	3216	5110	3781	69
H(5A)	1997	4109	3923	71
H(5B)	1927	4413	3054	71
H(7A)	2448	3288	1922	61
H(7B)	2797	2353	2156	61
H(8A)	4082	3049	2883	55
H(9A)	4877	3340	1852	61
H(9B)	4094	2660	1455	61
H(12A)	3514	4930	-367	74
H(13A)	5032	4388	3486	109
H(13B)	4739	5368	3329	109
H(13C)	5078	4720	2636	109
H(14A)	1880	1948	4324	127
H(14B)	2322	1282	3700	127
H(15A)	1259	1433	2788	99
H(15B)	723	1897	3469	99
H(16A)	4851	4150	-1293	136
H(16B)	3857	3788	-1577	136
H(16C)	4679	3191	-1774	136
H(17A)	3620	1828	-97	149
H(17B)	3865	1651	-981	149
H(17C)	3044	2251	-789	149
H(18A)	5951	3322	43	115
H(18B)	5779	2344	-402	115
H(18C)	5515	2555	473	115
H(44A)	8619	3665	704	68
H(44B)	7631	4004	754	68
H(45A)	8648	5227	677	75
H(45B)	8188	5356	1478	75
H(47A)	9154	4958	2783	64
H(47B)	10126	4602	2680	64
H(48A)	9531	3269	1985	57
H(49A)	9039	2574	3009	65
H(49B)	9687	3375	3427	65
H(52A)	7156	4227	4873	74
H(53A)	7269	2544	1298	105
H(53B)	7822	2288	2081	105
H(53C)	8279	2262	1280	105
H(54A)	11138	6088	2112	120
H(54B)	10797	6568	1350	120
H(55A)	10867	5365	578	142
H(55B)	11431	4978	1302	142
H(56A)	10309	3970	5051	155
H(56B)	10331	3719	5934	155
H(56C)	9799	4560	5676	155
H(57A)	9612	2098	4423	114
H(57B)	8727	1697	4712	114
H(57C)	9622	1824	5298	114

H(58A)	8639	2969	6530	139
H(58B)	7744	2800	5948	139
H(58C)	8086	3792	6262	139
H(24A)	7615	628	8862	68
H(24B)	6721	1047	9132	68
H(25A)	6799	-603	8149	70
H(25B)	6548	-518	9035	70
H(27A)	4761	437	7380	63
H(27B)	5635	12	7075	63
H(28A)	5598	1658	8064	55
H(29A)	5122	1710	6661	61
H(29B)	5892	2426	7020	61
H(32A)	7191	866	4702	74
H(33A)	7285	2527	7742	104
H(33B)	7966	2133	8381	104
H(33C)	7035	2490	8620	104
H(34A)	4105	-1624	8526	97
H(34B)	3796	-919	7919	97
H(35A)	3770	-6	9010	120
H(35B)	4464	-573	9508	120
H(36A)	4777	3334	4789	139
H(36B)	5760	3445	5237	139
H(36C)	4968	3034	5655	139
H(37A)	4552	589	4365	141
H(37B)	3971	1437	4224	141
H(37C)	4188	1156	5093	141
H(38A)	6107	1355	3554	119
H(38B)	6518	2329	3848	119
H(38C)	5546	2208	3380	119
H(64A)	8874	8958	4449	70
H(64B)	8410	9880	4336	70
H(65A)	7316	8738	4448	80
H(65B)	7142	9125	3615	80
H(67A)	7686	8151	2372	67
H(67B)	8164	7250	2540	67
H(68A)	9408	8043	3239	57
H(69A)	10053	8562	2192	61
H(69B)	9357	7788	1803	61
H(72A)	8124	10026	165	74
H(73A)	9819	10400	3794	98
H(73B)	10167	9844	3052	98
H(73C)	10240	9453	3885	98
H(74A)	6909	6135	3013	114
H(74B)	6262	6294	3699	114
H(75A)	7392	6513	4635	130
H(75B)	7939	5971	4001	130
H(76A)	8495	8907	-1162	145
H(76B)	9387	8472	-1420	145
H(76C)	9430	9438	-945	145
H(77A)	8074	7266	-311	139
H(77B)	8787	6961	352	139
H(77C)	8966	6814	-552	139
H(78A)	10818	8801	288	123
H(78B)	10765	7816	-152	123
H(78C)	10587	7975	752	123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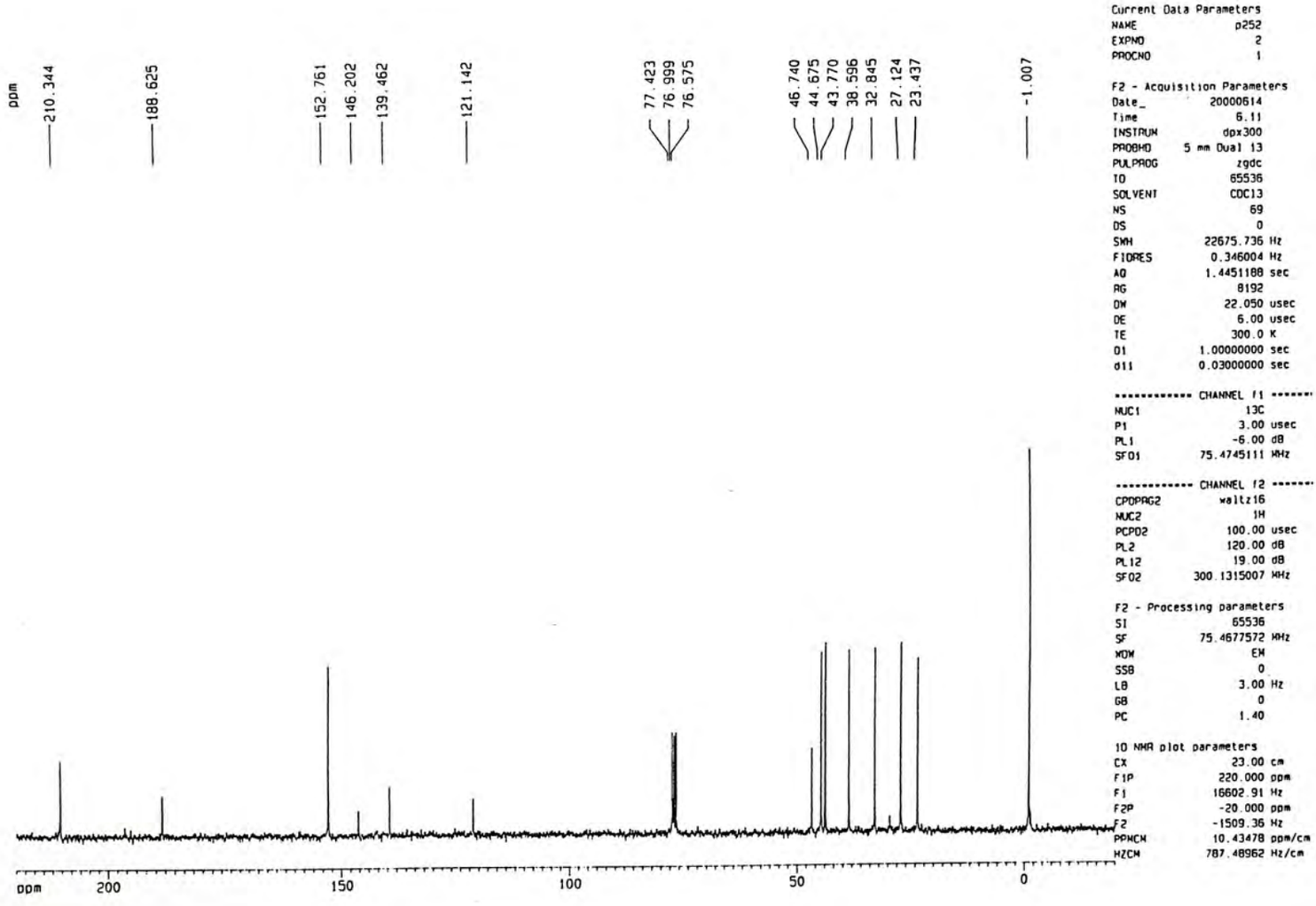
3.16586
3.15088
3.10839
3.09321
2.49189
2.48215
2.46691
2.45778
2.40961
2.40061
2.37304
2.35648
2.33480
2.31412
2.30782
2.30050
2.29432
2.26078
2.24704
1.51238
1.49465
1.33330
1.31101
1.20515
0.27630
0.25187
0.24551
0.23158
0.22128
(H3C)3Si
H
O
O
O
Current Data Parameters
NAME p252
EXPNO 1
PROCNO 1
F2 - Acquisition Parameters
Date_ 20000614
Time 6.07
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 16
DS 0
SWH 8992.806 Hz
FIDRES 0.274439 Hz
AQ 1.8219508 sec
RG 32
DW 55.600 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
CHANNEL f1
NUC1 1H
P1 4.50 usec
PL1 -2.00 dB
SFO1 300.1312000 MHz
F2 - Processing parameters
SI 32768
SF 300.1300057 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 0.50
1D NMR plot parameters
CX 23.00 cm
F1P 10.000 ppm
F1 3001.30 Hz
F2P -1.000 ppm
F2 -300.13 Hz
PPMCM 0.47826 ppm/cm
HZCM 143.54044 Hz/cm
Integral
1.0183
0.9867
1.0009
6.0803
1.0455
3.1596
9.0000
ppm
9
8
7
6
5
4
3
2
1
0

(±)-117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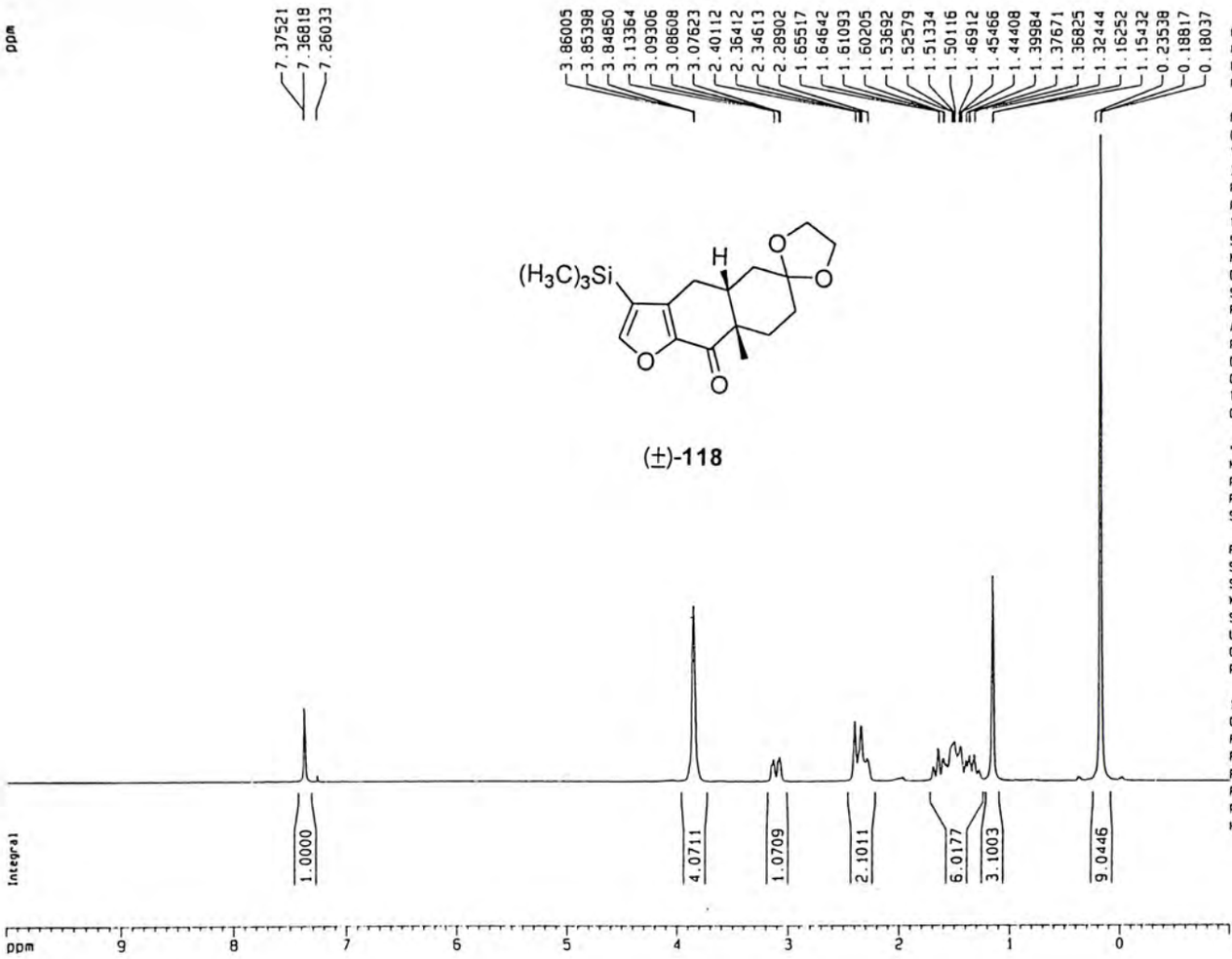
152.761
146.202
139.462
121.142
77.423
76.999
76.575
46.740
44.675
43.770
38.596
32.845
27.124
23.437
-1.007
Current Data Parameters
NAME p252
EXPNO 2
PROCNO 1
F2 - Acquisition Parameters
Date_ 20000614
Time 6.11
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zgdc
TD 65536
SOLVENT CDCl3
NS 69
DS 0
SWH 22675.736 Hz
FIDRES 0.346004 Hz
AQ 1.4451188 sec
RG 8192
DW 22.050 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
D11 0.03000000 sec
CHANNEL f1
NUC1 13C
P1 3.00 usec
PL1 -6.00 dB
SFO1 75.4745111 MHz
CHANNEL f2
CPDPRG2 waltz16
NUC2 1H
PCPD2 100.00 usec
PL2 120.00 dB
PL12 19.00 dB
SFO2 300.1315007 MHz
F2 - Processing parameters
SI 65536
SF 75.4677572 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 1.40
1D NMR plot parameters
CX 23.00 cm
F1P 220.000 ppm
F1 16602.91 Hz
F2P -20.000 ppm
F2 -1509.36 Hz
PPMCM 10.43478 ppm/cm
HZCM 787.48962 Hz/cm
ppm
200
150
100
50
0



(±)-**118**

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Current Data Parameters
NAME                  p251
EXPNO                    1
PROCNO                   1

F2 - Acquisition Parameters
Date_              20000614
Time                 6.58
INSTRUM             dpx300
PROBHD     5 mm Dual 13
PULPROG                zg
TD                  32768
SOLVENT             CDCl3
NS                      16
DS                       0
SWH              8992.806 Hz
FIDRES           0.274439 Hz
AQ               1.8219508 sec
RG                      32
DW                55.600 usec
DE                 6.00 usec
TE                300.0 K
D1             1.00000000 sec

============ CHANNEL f1 =======
NUC1                   1H
P1                 4.50 usec
PL1                -2.00 dB
SFO1        300.1312000 MHz

F2 - Processing parameters
SI                  32768
SF          300.1300063 MHz
WDW                    EM
SSB                     0
LB                 0.30 Hz
GB                      0
PC                   1.00

1D NMR plot parameters
CX                 23.00 cm
F1P               10.000 ppm
F1              3001.30 Hz
F2P               -1.000 ppm
F2              -300.13 Hz
PPMCM             0.47826 ppm/cm
HZCM            143.54044 Hz/cm
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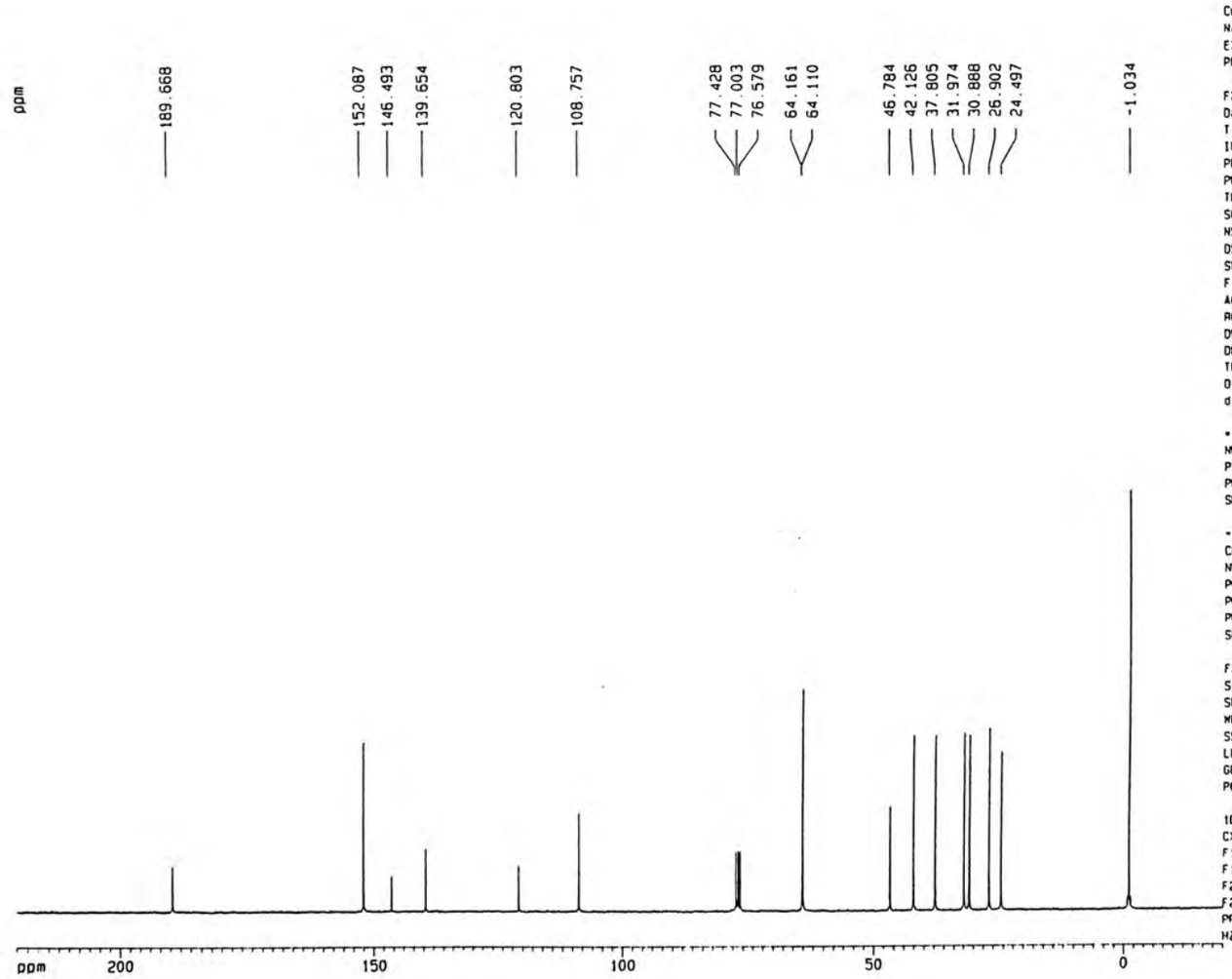


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Current Data Parameters
NAME                  p251
EXPNO                    2
PROCNO                   1

F2 - Acquisition Parameters
Date_              20000614
Time                 7.12
INSTRUM             dpx300
PROBHD     5 mm Dual 13
PULPROG             zgdc
TD                  65536
SOLVENT             CDCl3
NS                     416
DS                       0
SWH              22675.736 Hz
FIDRES           0.346004 Hz
AQ               1.4451188 sec
RG                    8192
DW                22.050 usec
DE                 6.00 usec
TE                300.0 K
D1             1.00000000 sec
D11            0.03000000 sec

============ CHANNEL f1 =======
NUC1                  13C
P1                 3.00 usec
PL1                -6.00 dB
SFO1         75.4745111 MHz

============ CHANNEL f2 =======
CPDPRG2           waltz16
NUC2                   1H
PCPD2             100.00 usec
PL2                120.00 dB
PL12                19.00 dB
SFO2        300.1315007 MHz

F2 - Processing parameters
SI                  65536
SF           75.4677583 MHz
WDW                    EM
SSB                     0
LB                 3.00 Hz
GB                      0
PC                   1.40

1D NMR plot parameters
CX                 23.00 cm
F1P               220.000 ppm
F1              16602.91 Hz
F2P               -20.000 ppm
F2              -1509.36 Hz
PPMCM            10.43478 ppm/cm
HZCM            787.48962 Hz/cm
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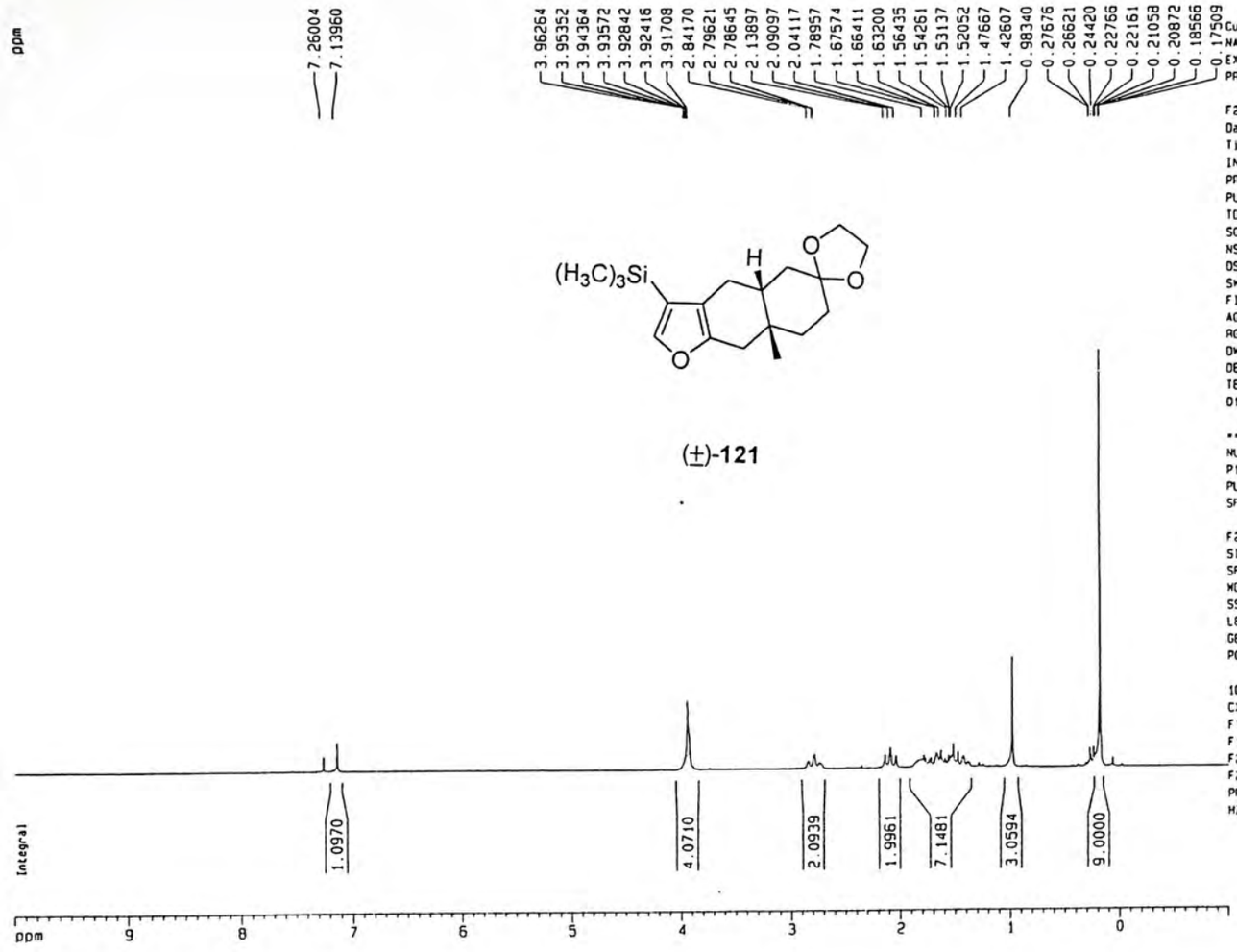
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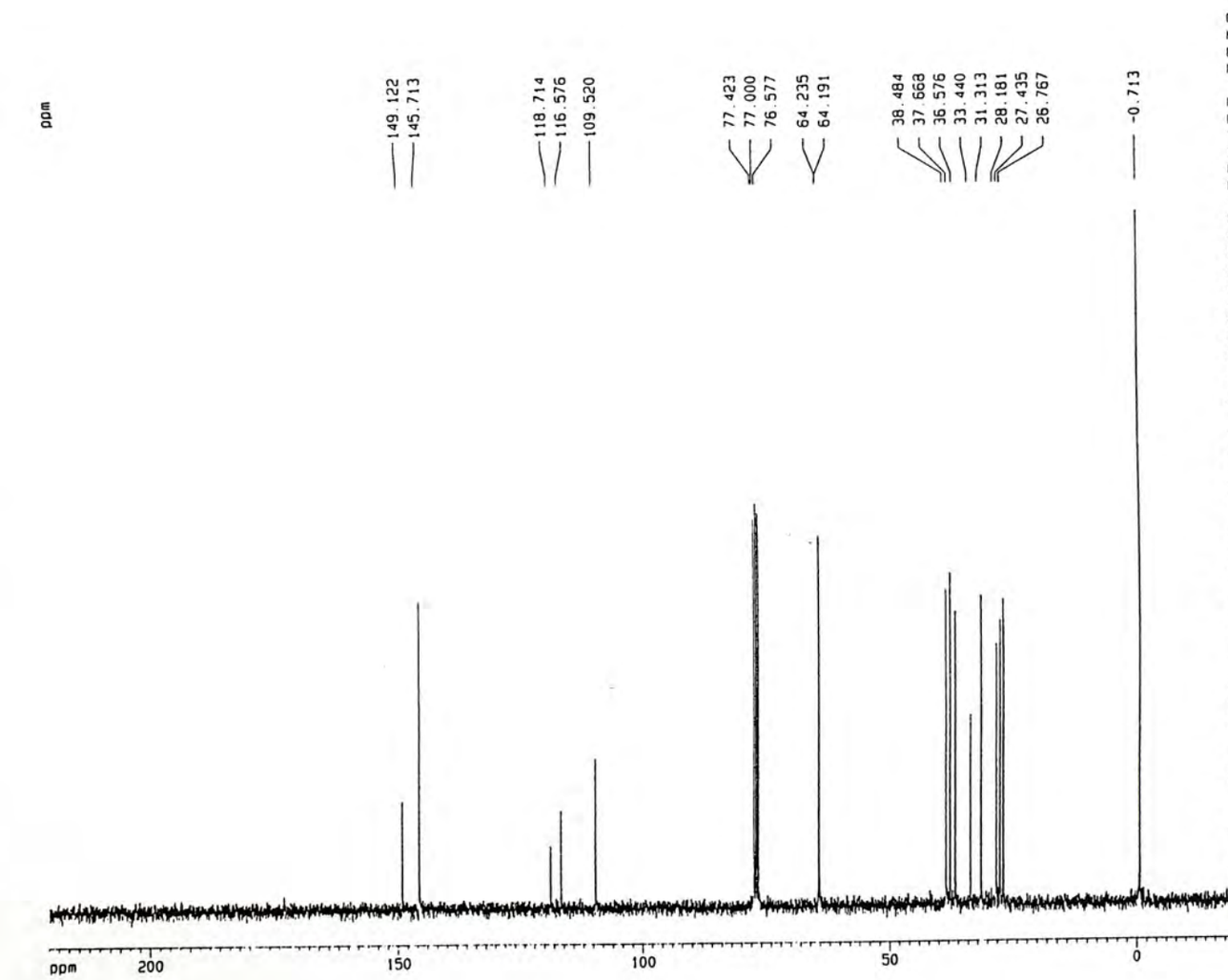
3.96264
3.95352
3.94364
3.93572
3.92842
3.92416
3.91708
2.84170
2.79621
2.78645
2.13897
2.09097
2.04117
1.78957
1.67574
1.66411
1.63200
1.56435
1.54261
1.53137
1.52052
1.47667
1.42607
0.98340
0.27676
0.26621
0.24420
0.22766
0.22161
0.21058
0.20872
0.18566
0.17509
Current Data Parameters
NAME 5o50c6lt4-6
EXPNO 1
PROCNO 1
F2 - Acquisition Parameters
Date_ 20010329
Time 14.01
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 16
DS 0
SWH 8992.806 Hz
FIDRES 0.274439 Hz
AQ 1.8219508 sec
RG 143.7
DW 55.600 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
CHANNEL f1
NUC1 1H
P1 4.50 usec
PL1 -2.00 dB
SFO1 300.1312000 MHz
F2 - Processing parameters
SI 32768
SF 300.1300060 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00
1D NMR plot parameters
CX 23.00 cm
F1P 10.000 ppm
F1 3001.30 Hz
F2P -1.000 ppm
F2 -300.13 Hz
PPMCM 0.47826 ppm/cm
HZCM 143.54044 Hz/cm
(H3C)3Si
H
O
O
O
(±)-121
Integral
1.0970
4.0710
2.0939
1.9961
7.1481
3.0594
9.0000
ppm
9
8
7
6
5
4
3
2
1
0


ppm
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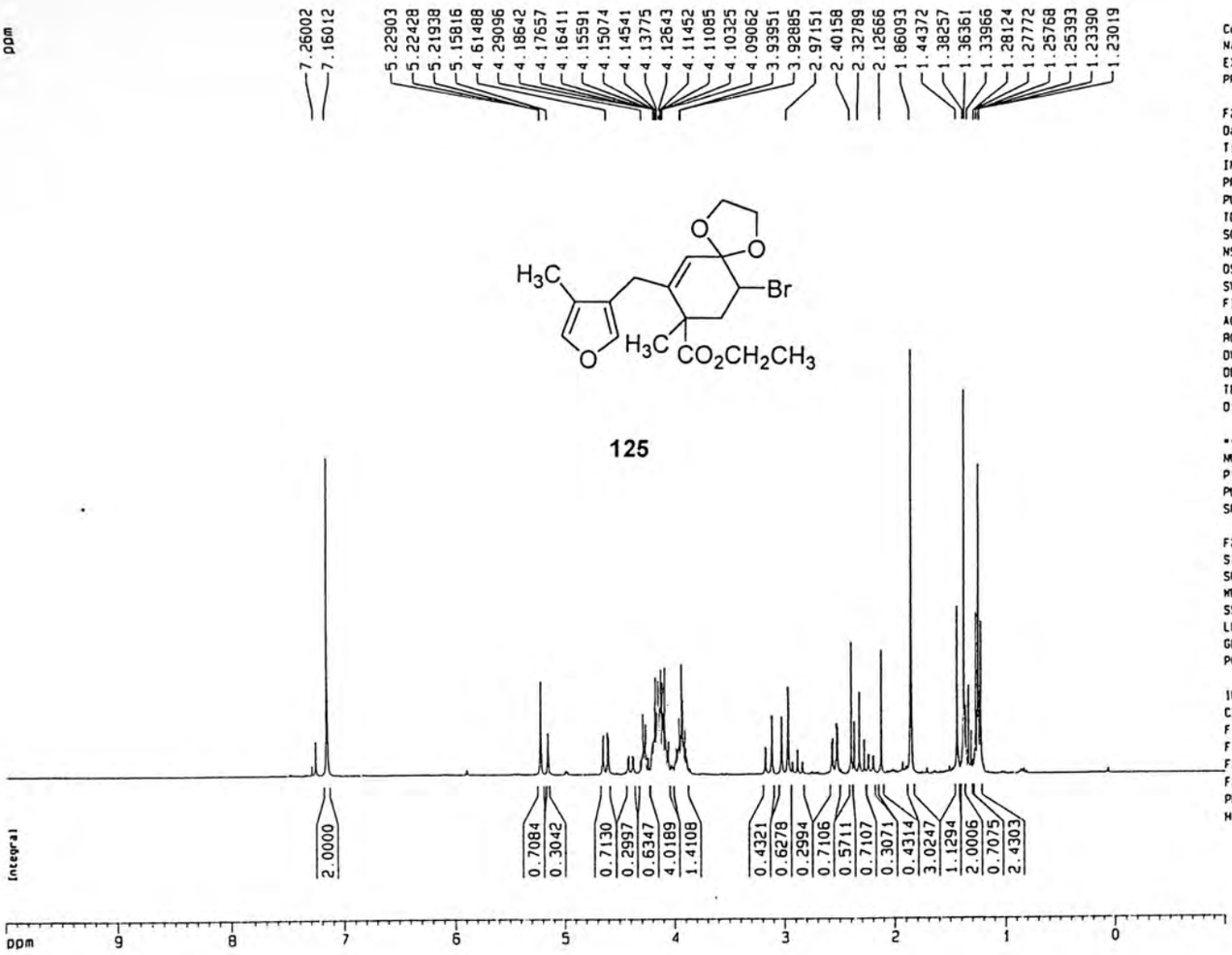
118.714
116.576
109.520
77.423
77.000
76.577
64.235
64.191
38.484
37.668
36.576
33.440
31.313
28.181
27.435
26.767
-0.713
Current Data Parameters
NAME 5o50c6lt4-6
EXPNO 2
PROCNO 1
F2 - Acquisition Parameters
Date_ 20010329
Time 14.07
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zgdc
TD 65536
SOLVENT CDCl3
NS 1150
DS 0
SWH 22675.736 Hz
FIDRES 0.346004 Hz
AQ 1.4451188 sec
RG 8192
DW 22.050 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
D11 0.03000000 sec
CHANNEL f1
NUC1 13C
P1 3.00 usec
PL1 -6.00 dB
SFO1 75.4745111 MHz
CHANNEL f2
CPDPRG2 waltz16
NUC2 1H
PCPD2 100.00 usec
PL2 120.00 dB
PL12 19.00 dB
SFO2 300.1315007 MHz
F2 - Processing parameters
SI 65536
SF 75.4677496 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40
1D NMR plot parameters
CX 23.00 cm
F1P 220.000 ppm
F1 16602.90 Hz
F2P -20.000 ppm
F2 -1509.36 Hz
PPMCM 10.43478 ppm/cm
HZCM 787.48956 Hz/cm
ppm
200
150
100
50
0



125

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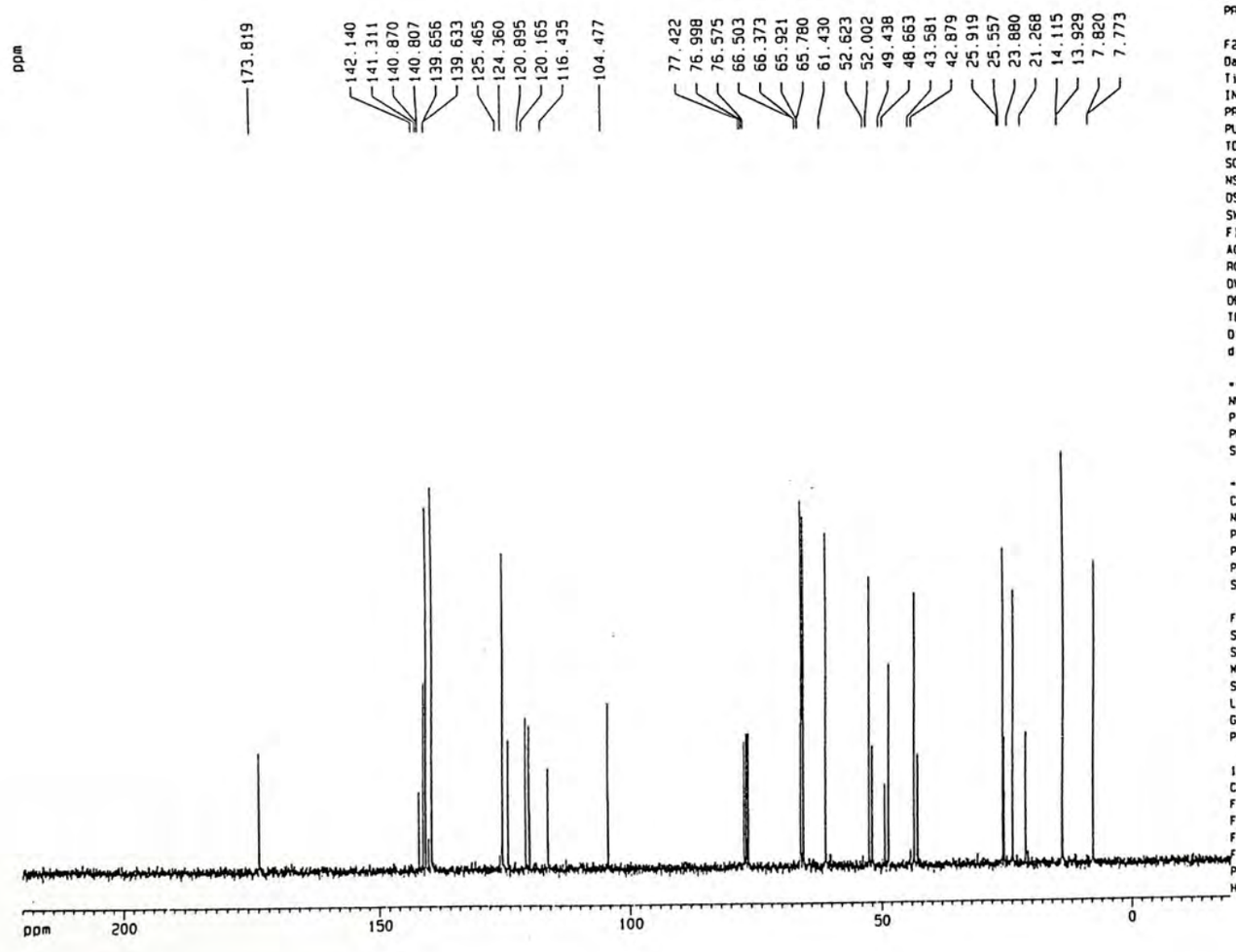
Current Data Parameters
NAME            coupling
EXPNO                  1
PROCNO                 1

F2 - Acquisition Parameters
Date_           20010712
Time               15.25
INSTRUM           dpx300
PROBHD   5 mm Dual 13
PULPROG               zg
TD                 32768
SOLVENT           CDCl3
NS                     8
DS                     0
SWH           8992.806 Hz
FIDRES        0.274439 Hz
AQ            1.8219508 sec
RG                    16
DW               55.600 usec
DE                6.00 usec
TE               300.0 K
D1            1.00000000 sec

========== CHANNEL f1 =======
NUC1                  1H
P1                4.50 usec
PL1              -2.00 dB
SFO1         300.1312000 MHz

F2 - Processing parameters
SI                 32768
SF            300.1299953 MHz
WDW                   EM
SSB                    0
LB                0.30 Hz
GB                     0
PC                  1.00

1D NMR plot parameters
CX                23.00 cm
F1P               10.000 ppm
F1              3001.30 Hz
F2P               -1.000 ppm
F2              -300.13 Hz
PPMCM             0.47826 ppm/cm
HZCM            143.54044 Hz/cm
```

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Current Data Parameters
NAME            coupling
EXPNO                  2
PROCNO                 1

F2 - Acquisition Parameters
Date_           20010712
Time               15.26
INSTRUM           dpx300
PROBHD   5 mm Dual 13
PULPROG            zgdc
TD                 65536
SOLVENT           CDCl3
NS                    41
DS                     0
SWH          22675.736 Hz
FIDRES        0.346004 Hz
AQ            1.4451188 sec
RG                  8192
DW               22.050 usec
DE                6.00 usec
TE               300.0 K
D1            1.00000000 sec
D11           0.03000000 sec

========== CHANNEL f1 =======
NUC1                  13C
P1                3.00 usec
PL1              -6.00 dB
SFO1         75.4745111 MHz

========== CHANNEL f2 =======
CPDPRG2           waltz16
NUC2                  1H
PCPD2            100.00 usec
PL2              120.00 dB
PL12              19.00 dB
SFO2         300.1315007 MHz

F2 - Processing parameters
SI                 65536
SF            75.4677631 MHz
WDW                   EM
SSB                    0
LB                1.00 Hz
GB                     0
PC                  1.40

1D NMR plot parameters
CX                23.00 cm
F1P              220.000 ppm
F1             16602.91 Hz
F2P              -20.000 ppm
F2             -1509.35 Hz
PPMCM            10.43478 ppm/cm
HZCM           787.48969 Hz/cm
```

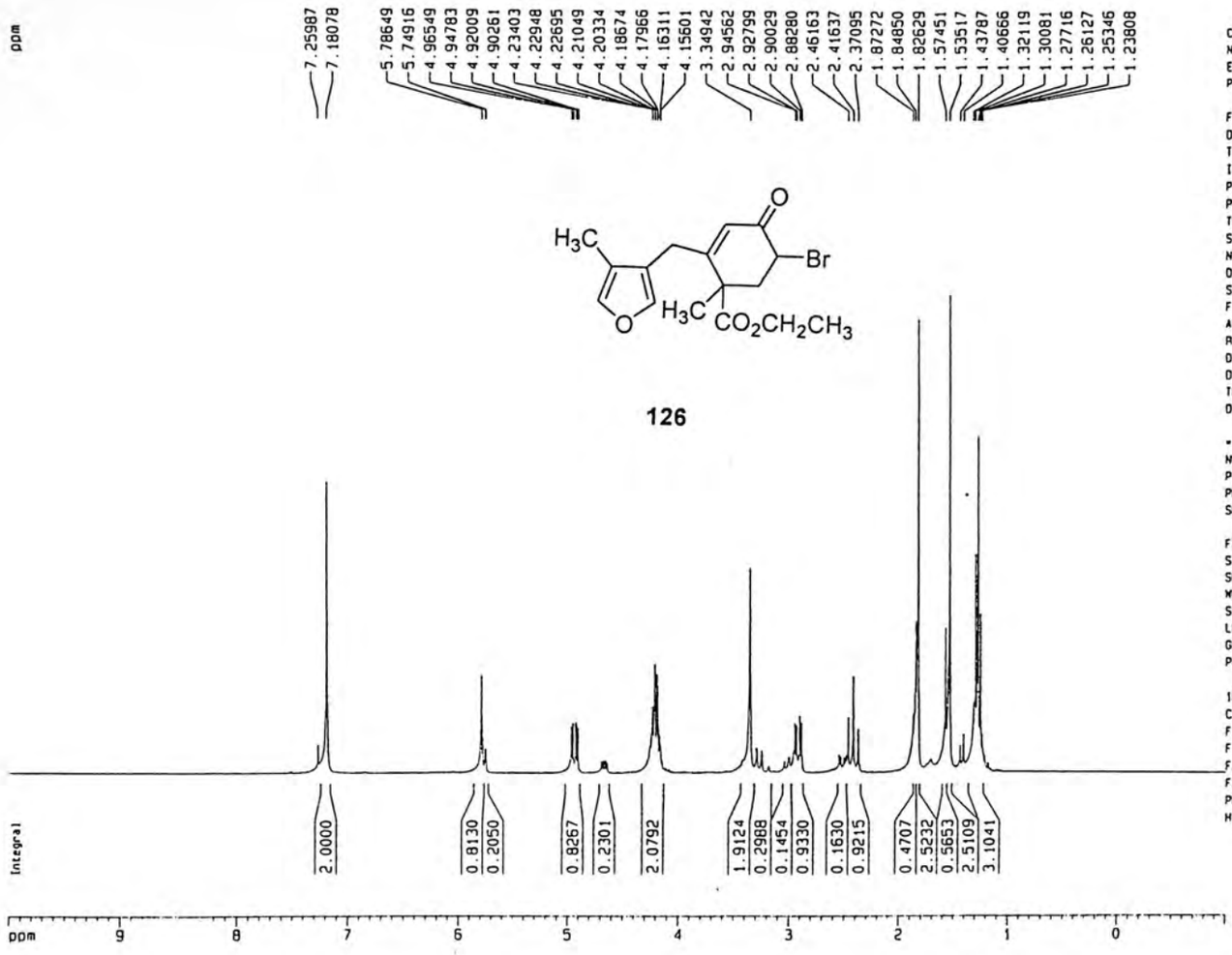

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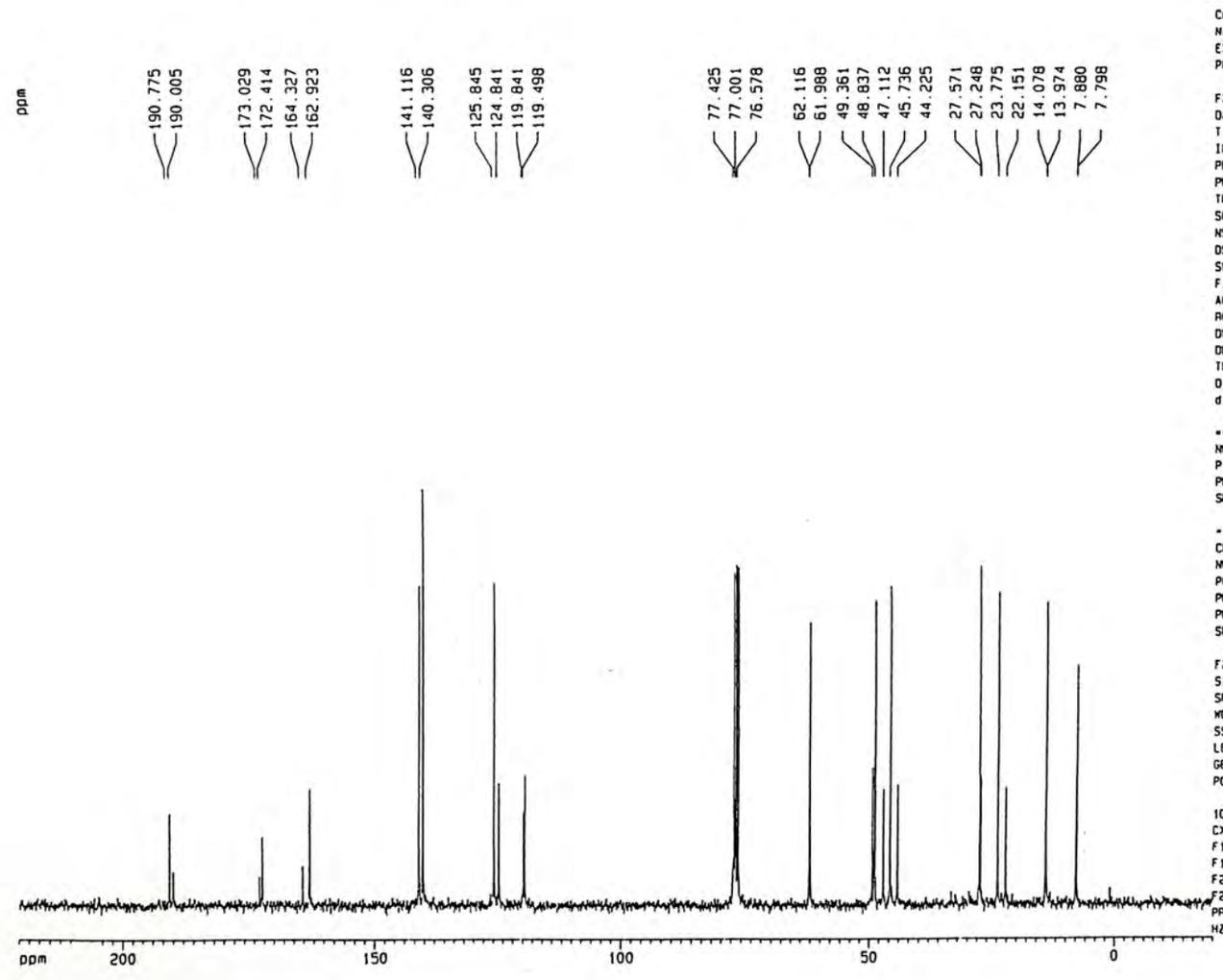
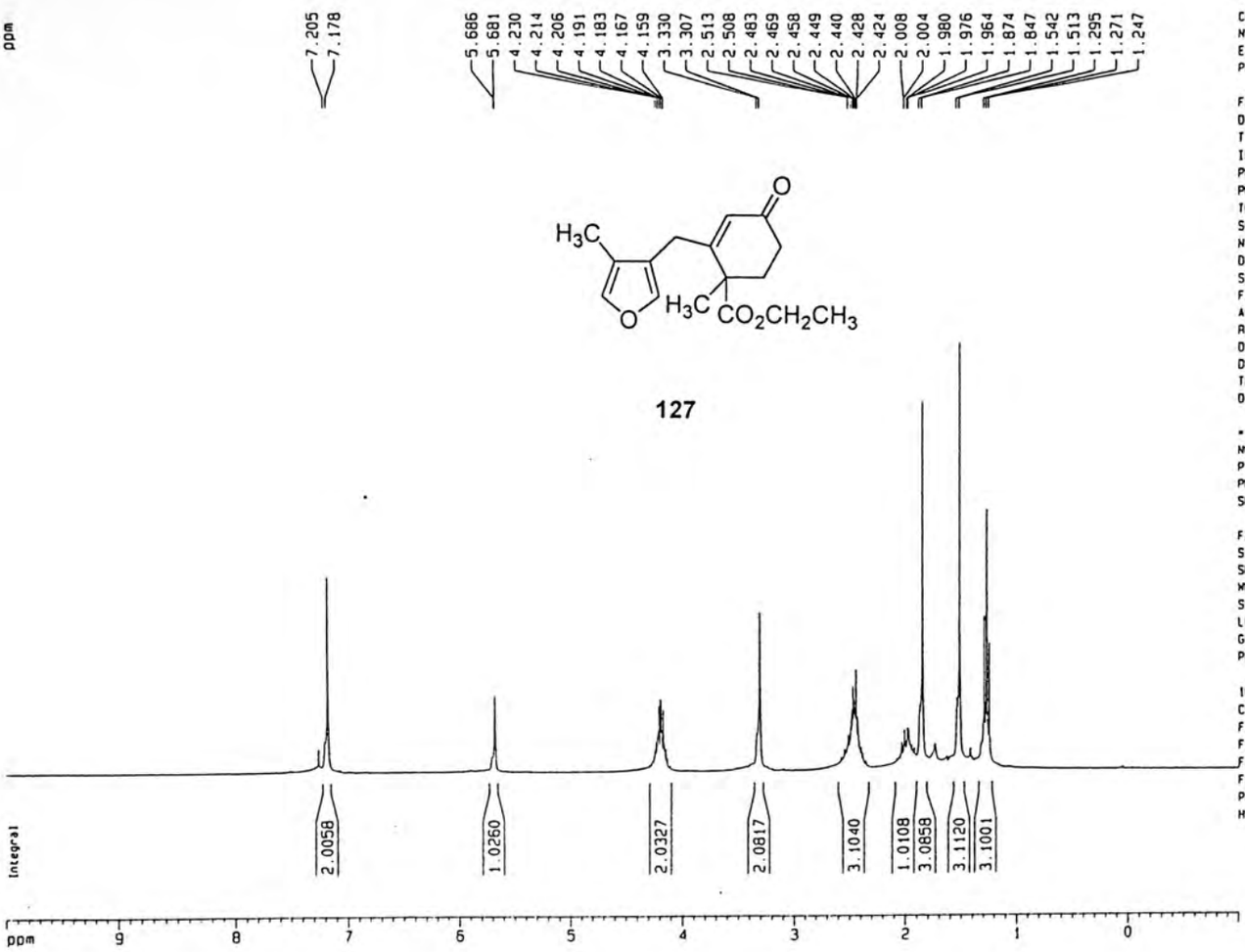
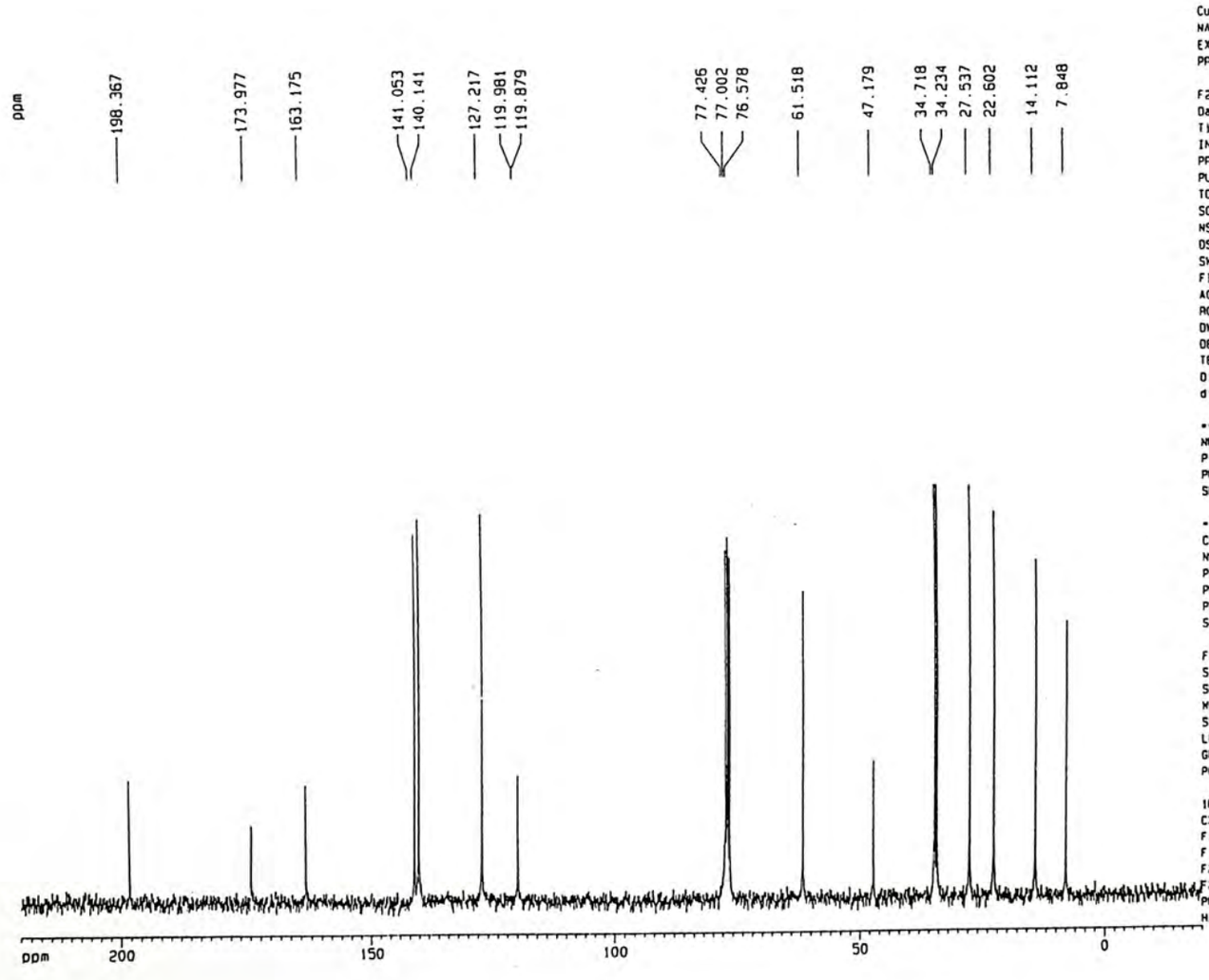
```
Current Data Parameters
NAME          2p246product
EXPNO                    1
PROCNO                   1

F2 - Acquisition Parameters
Date_              20000511
Time                   9.52
INSTRUM              dpx300
PROBHD     5 mm Dual 13
PULPROG                 zg
TD                   32768
SOLVENT              CDCl3
NS                      16
DS                       0
SWH               8992.806 Hz
FIDRES            0.274439 Hz
AQ                1.8219508 sec
RG                      64
DW                55.600 usec
DE                 6.00 usec
TE                 300.0 K
D1                1.00000000 sec

============ CHANNEL f1 =======
NUC1                    1H
P1                 4.50 usec
PL1                -2.00 dB
SF01          300.1312000 MHz

F2 - Processing parameters
SI                   32768
SF            300.1300060 MHz
WDW                     EM
SSB                      0
LB                 0.30 Hz
GB                       0
PC                 1.00

1D NMR plot parameters
CX                 23.00 cm
F1P               10.000 ppm
F1              3001.30 Hz
F2P               -1.000 ppm
F2              -300.13 Hz
PPMCM             0.47826 ppm/cm
HZCM            143.54044 Hz/cm
```



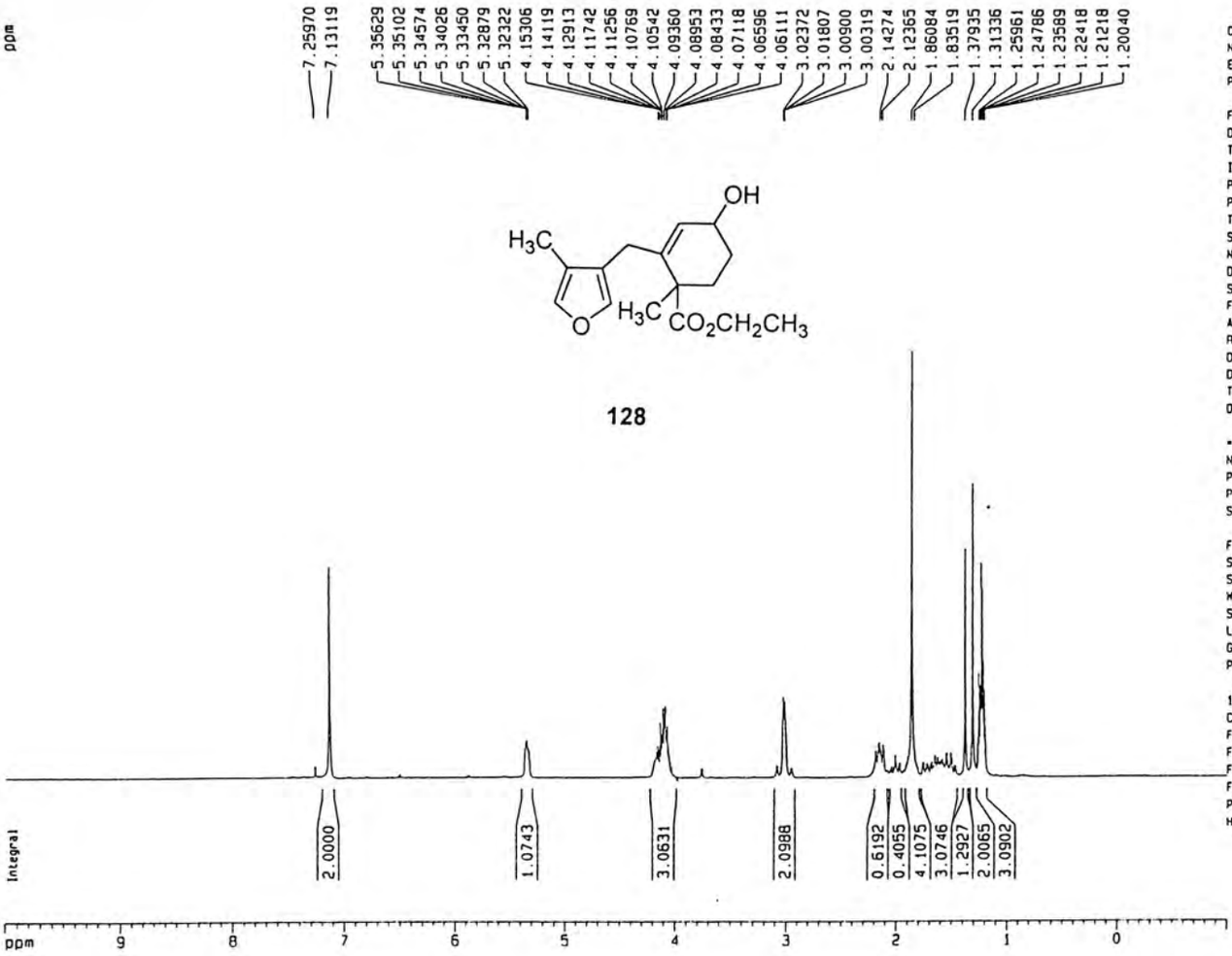

```
Current Data Parameters
NAME                  p246
EXPNO                    2
PROCNO                   1

F2 - Acquisition Parameters
Date_              20000614
Time                   1.13
INSTRUM              dpx300
PROBHD     5 mm Dual 13
PULPROG               zgdc
TD                   65536
SOLVENT              CDCl3
NS                     722
DS                       0
SWH              22675.736 Hz
FIDRES            0.346004 Hz
AQ                1.4451188 sec
RG                    8192
DW                22.050 usec
DE                 6.00 usec
TE                 300.0 K
D1                1.00000000 sec
D11               0.03000000 sec

============ CHANNEL f1 =======
NUC1                   13C
P1                 3.00 usec
PL1                -6.00 dB
SF01          75.4745111 MHz

============ CHANNEL f2 =======
CPDPRG2            waltz16
NUC2                    1H
PCPD2             100.00 usec
PL2               120.00 dB
PL12               19.00 dB
SF02          300.1315007 MHz

F2 - Processing parameters
SI                   65536
SF            75.4677548 MHz
WDW                     EM
SSB                      0
LB                 3.00 Hz
GB                       0
PC                 1.40

1D NMR plot parameters
CX                 23.00 cm
F1P               220.000 ppm
F1              16602.91 Hz
F2P               -20.000 ppm
F2              -1509.36 Hz
PPMCM             10.43478 ppm/cm
HZCM            787.48962 Hz/cm
```



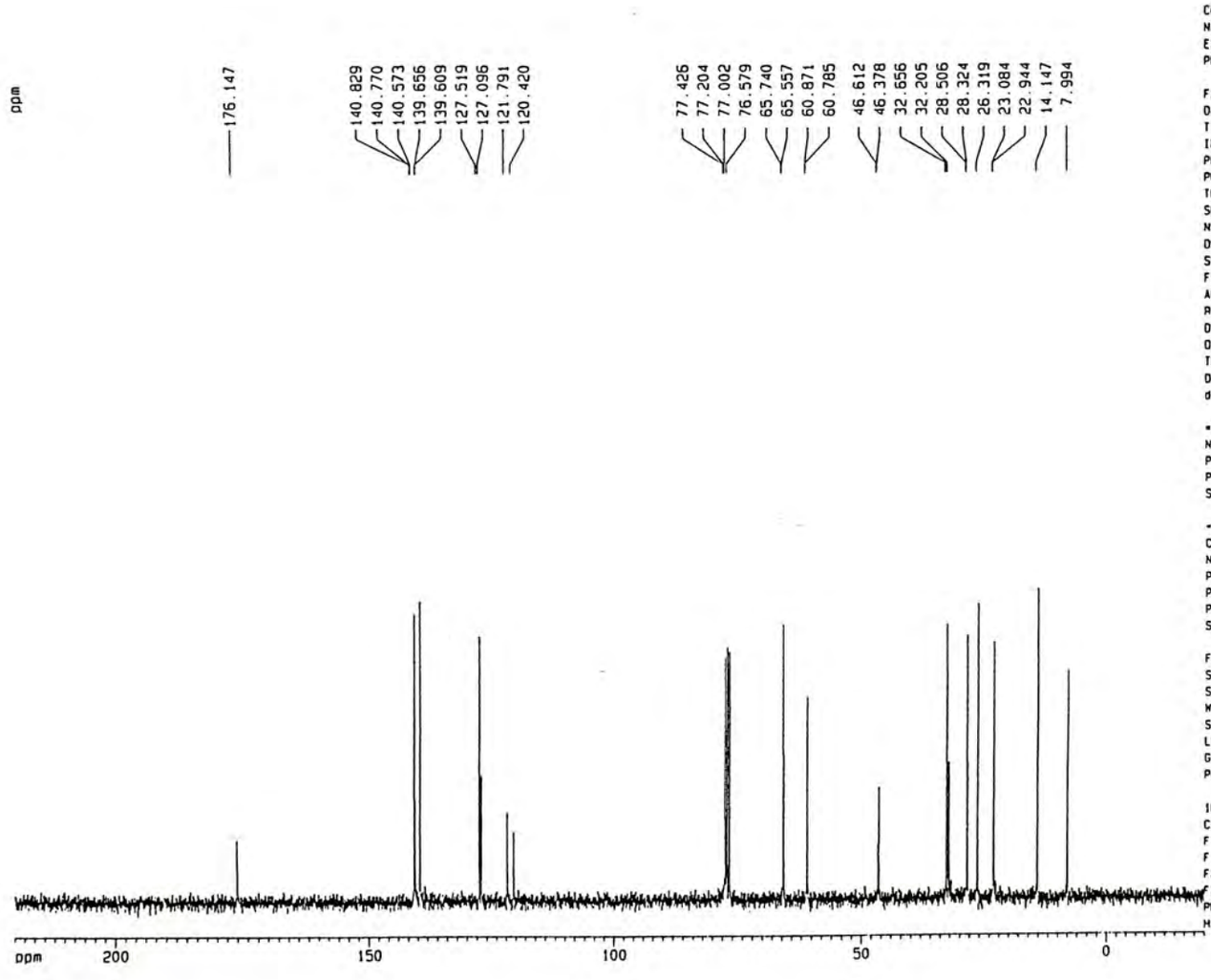

```
Current Data Parameters
NAME                  p247
EXPNO                    1
PROCNO                   1

F2 - Acquisition Parameters
Date_              20000613
Time                 23.01
INSTRUM             dpx300
PROBHD     5 mm Dual 13
PULPROG                zg
TD                  32768
SOLVENT             CDCl3
NS                     16
DS                      0
SWH              8992.806 Hz
FIDRES           0.274439 Hz
AQ               1.8219508 sec
RG                   101.6
DW                55.600 usec
DE                 6.00 usec
TE                 300.0 K
D1              1.00000000 sec

------------ CHANNEL f1 -------
NUC1                   1H
P1                 4.50 usec
PL1                -2.00 dB
SFO1          300.1312000 MHz

F2 - Processing parameters
SI                  32768
SF            300.1300057 MHz
WDW                    EM
SSB                     0
LB                 0.30 Hz
GB                      0
PC                   1.00

1D NMR plot parameters
CX                 23.00 cm
F1P               10.000 ppm
F1              3001.30 Hz
F2P               -1.000 ppm
F2              -300.13 Hz
PPMCM            0.47826 ppm/cm
HZCM           143.54044 Hz/cm
```



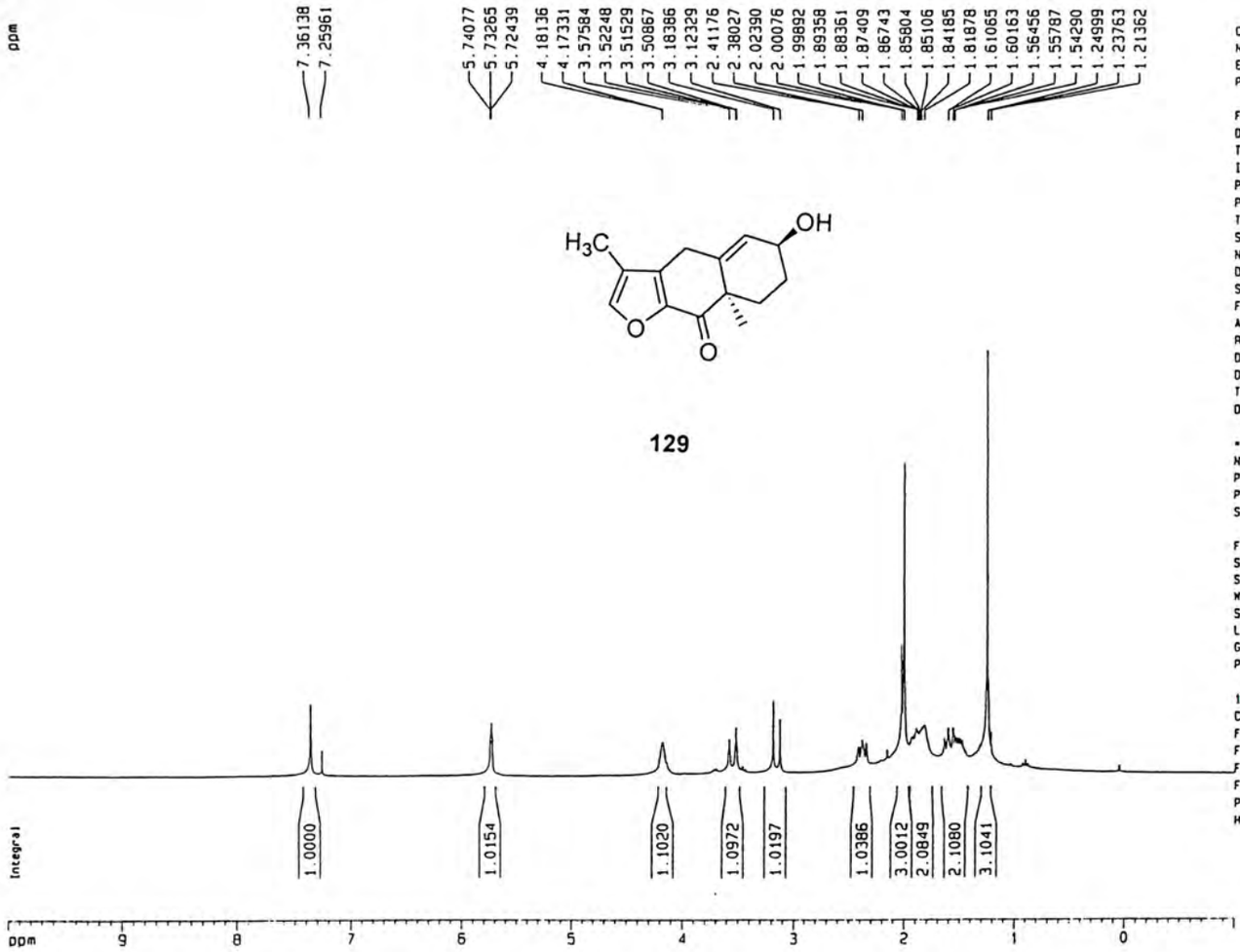

```
Current Data Parameters
NAME                  p247
EXPNO                    2
PROCNO                   1

F2 - Acquisition Parameters
Date_              20000613
Time                 23.23
INSTRUM             dpx300
PROBHD     5 mm Dual 13
PULPROG             zgdc
TD                  65536
SOLVENT             CDCl3
NS                    513
DS                      0
SWH             22675.736 Hz
FIDRES           0.346004 Hz
AQ               1.4451188 sec
RG                   8192
DW                22.050 usec
DE                 6.00 usec
TE                 300.0 K
D1              1.00000000 sec
D11             0.03000000 sec

------------ CHANNEL f1 -------
NUC1                   13C
P1                 3.00 usec
PL1                -6.00 dB
SFO1          75.4745111 MHz

------------ CHANNEL f2 -------
CPDPRG2            waltz16
NUC2                   1H
PCPD2             100.00 usec
PL2                120.00 dB
PL12               19.00 dB
SFO2          300.1315007 MHz

F2 - Processing parameters
SI                  65536
SF            75.4677538 MHz
WDW                    EM
SSB                     0
LB                 3.00 Hz
GB                      0
PC                   1.40

1D NMR plot parameters
CX                 23.00 cm
F1P               220.000 ppm
F1              16602.90 Hz
F2P               -20.000 ppm
F2              -1509.36 Hz
PPMCM           10.43478 ppm/cm
HZCM           787.48956 Hz/cm
```




```
Current Data Parameters
NAME                  p249
EXPNO                    1
PROCNO                   1

F2 - Acquisition Parameters
Date_              20000613
Time                 23.46
INSTRUM              dpx300
PROBHD     5 mm Dual 13
PULPROG                zg
TD                  32768
SOLVENT             CDCl3
NS                       8
DS                       0
SWH               8992.806 Hz
FIDRES            0.274439 Hz
AQ                1.8219508 sec
RG                      32
DW                 55.600 usec
DE                  6.00 usec
TE                 300.0 K
D1                1.00000000 sec

============ CHANNEL f1 =======
NUC1                    1H
P1                  4.50 usec
PL1                -2.00 dB
SFO1          300.1312000 MHz

F2 - Processing parameters
SI                      32768
SF                300.1300063 MHz
WDW                        EM
SSB                         0
LB                   0.30 Hz
GB                          0
PC                       1.00

1D NMR plot parameters
CX                  23.00 cm
F1P                10.000 ppm
F1                 3001.30 Hz
F2P                -1.000 ppm
F2                 -300.13 Hz
PPMCM             0.47826 ppm/cm
HZCM              143.54044 Hz/cm
```




```
Current Data Parameters
NAME          5p92citt7stms
EXPNO                    2
PROCNO                   1

F2 - Acquisition Parameters
Date_              20010523
Time                 13.35
INSTRUM              dpx300
PROBHD     5 mm Dual 13
PULPROG             zgdc
TD                  65536
SOLVENT             CDCl3
NS                     489
DS                       0
SWH              22675.736 Hz
FIDRES            0.346004 Hz
AQ                1.4451188 sec
RG                    8192
DW                 22.050 usec
DE                  6.00 usec
TE                 300.0 K
D1                1.00000000 sec
D11               0.03000000 sec

============ CHANNEL f1 =======
NUC1                    13C
P1                  3.00 usec
PL1                -6.00 dB
SFO1          75.4745111 MHz

============ CHANNEL f2 =======
CPDPRG2             waltz16
NUC2                    1H
PCPD2              100.00 usec
PL2                120.00 dB
PL12                19.00 dB
SFO2          300.1315007 MHz

F2 - Processing parameters
SI                      65536
SF                75.4677531 MHz
WDW                        EM
SSB                         0
LB                   1.00 Hz
GB                          0
PC                       1.40

1D NMR plot parameters
CX                  23.00 cm
F1P                220.000 ppm
F1                 16602.90 Hz
F2P                -20.000 ppm
F2                 -1509.36 Hz
PPMCM             10.43478 ppm/cm
HZCM              787.48956 Hz/cm
```



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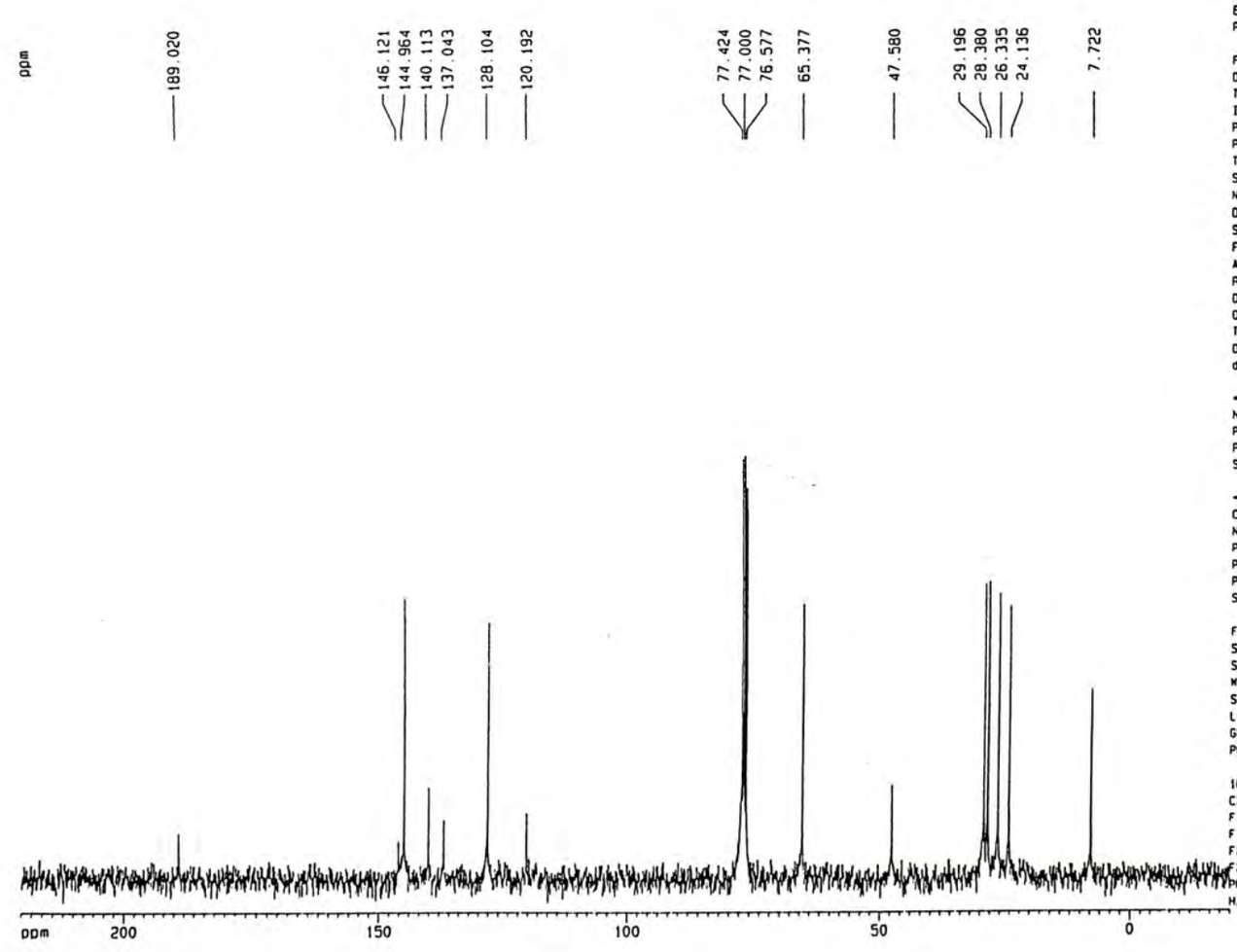
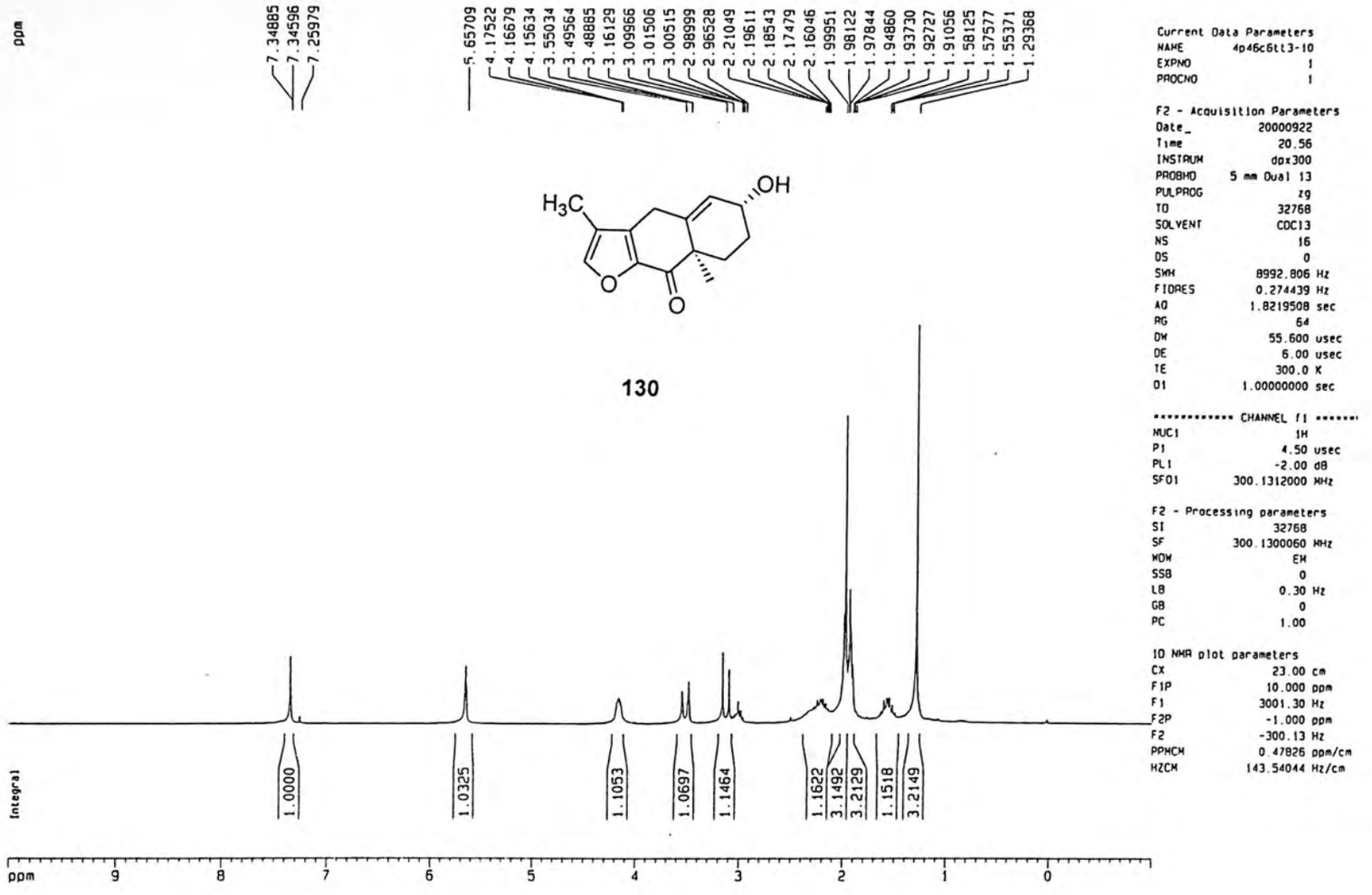
```
Current Data Parameters
NAME            c260tt6-8
EXPNO                   1
PROCNO                  1

F2 - Acquisition Parameters
Date_           20000626
Time               16.26
INSTRUM           dpx300
PROBHD     5 mm Dual 13
PULPROG                zg
TD                  32768
SOLVENT           Aceton
NS                      16
DS                       0
SWH             8992.806 Hz
FIDRES          0.274439 Hz
AQ              1.8219508 sec
RG                  143.7
DW                 55.600 usec
DE                  6.00 usec
TE                 300.0 K
D1              1.00000000 sec

========== CHANNEL f1 =======
NUC1                   1H
P1                  4.50 usec
PL1                -2.00 dB
SFO1           300.1312000 MHz

F2 - Processing parameters
SI                  32768
SF             300.1300066 MHz
WDW                    EM
SSB                     0
LB                   0.30 Hz
GB                      0
PC                   1.00

1D NMR plot parameters
CX                 23.00 cm
F1P                10.000 ppm
F1               3001.30 Hz
F2P                -1.000 ppm
F2               -300.13 Hz
PPMCM            0.47826 ppm/cm
HZCM           143.54044 Hz/cm
```




```
Current Data Parameters
NAME            c260tt6-8
EXPNO                   2
PROCNO                  1

F2 - Acquisition Parameters
Date_           20000626
Time               16.16
INSTRUM           dpx300
PROBHD     5 mm Dual 13
PULPROG              zgdc
TD                  65536
SOLVENT           CDCl3
NS                    557
DS                       0
SWH            22675.736 Hz
FIDRES          0.346004 Hz
AQ              1.4451188 sec
RG                   8192
DW                 22.050 usec
DE                  6.00 usec
TE                 300.0 K
D1              1.00000000 sec
D11             0.03000000 sec

========== CHANNEL f1 =======
NUC1                   13C
P1                  3.00 usec
PL1                -6.00 dB
SFO1           75.4745111 MHz

========== CHANNEL f2 =======
CPDPRG2            waltz16
NUC2                   1H
PCPD2              100.00 usec
PL2                120.00 dB
PL12                19.00 dB
SFO2           300.1315007 MHz

F2 - Processing parameters
SI                  65536
SF             75.4677538 MHz
WDW                    EM
SSB                     0
LB                   3.00 Hz
GB                      0
PC                   1.40

1D NMR plot parameters
CX                 23.00 cm
F1P                220.000 ppm
F1              16602.90 Hz
F2P                -20.000 ppm
F2              -1509.36 Hz
PPMCM           10.43478 ppm/cm
HZCM           787.48956 Hz/cm
```



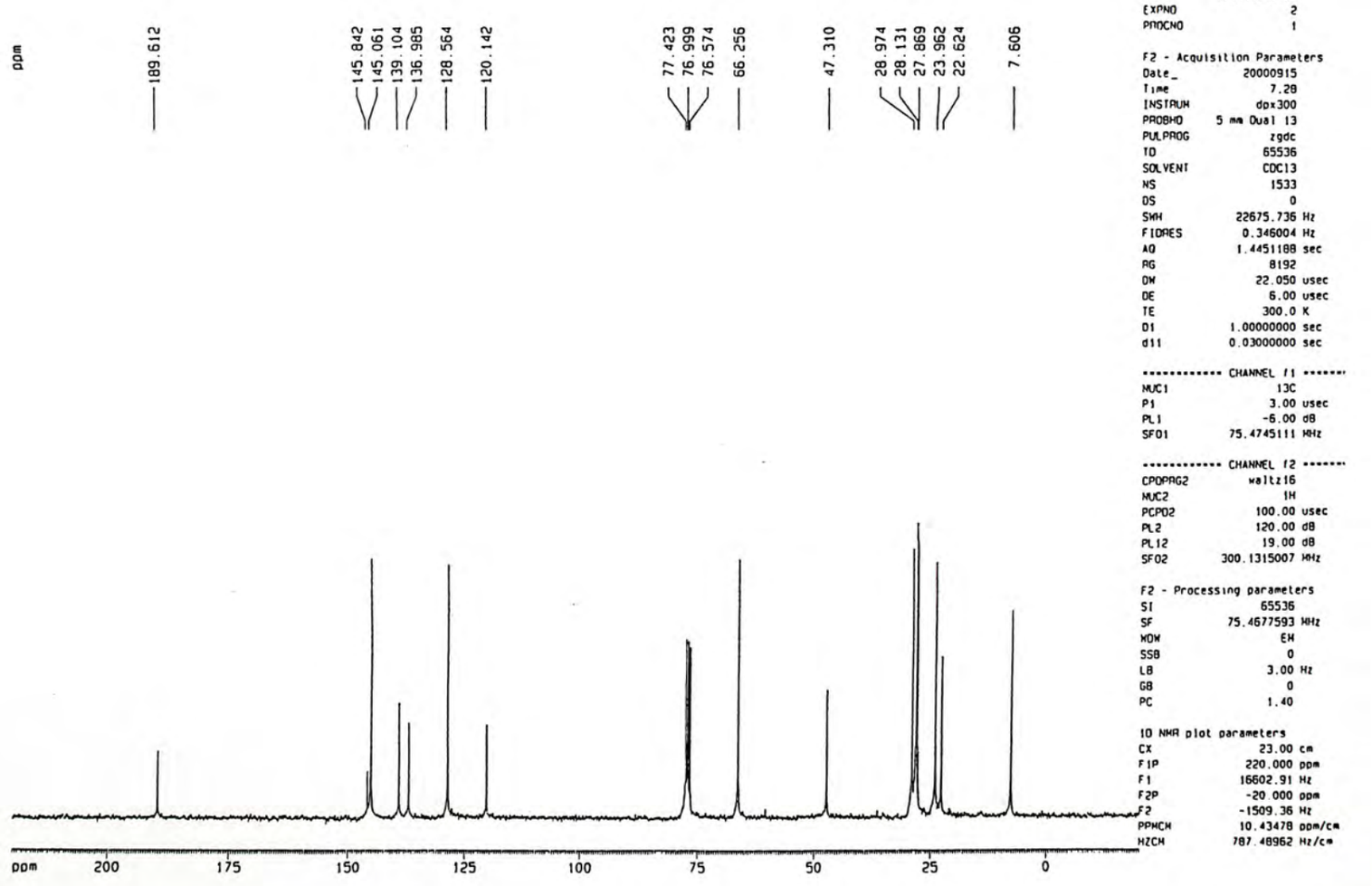
Current Data Parameters
NAME 4p46c6tt3-10
EXPNO 1
PROCNO 1

F2 - Acquisition Parameters
Date_ 20000922
Time 20.56
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 16
DS 0
SWH 8992.806 Hz
FIDRES 0.274439 Hz
AQ 1.8219508 sec
RG 64
DW 55.600 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec

********** CHANNEL f1 *******
NUC1 1H
P1 4.50 usec
PL1 -2.00 dB
SFO1 300.1312000 MHz

F2 - Processing parameters
SI 32768
SF 300.1300060 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

1D NMR plot parameters
CX 23.00 cm
F1P 10.000 ppm
F1 3001.30 Hz
F2P -1.000 ppm
F2 -300.13 Hz
PPMCM 0.47826 ppm/cm
HZCM 143.54044 Hz/cm



Current Data Parameters
NAME 4p42tt3-10L5
EXPNO 2
PROCNO 1

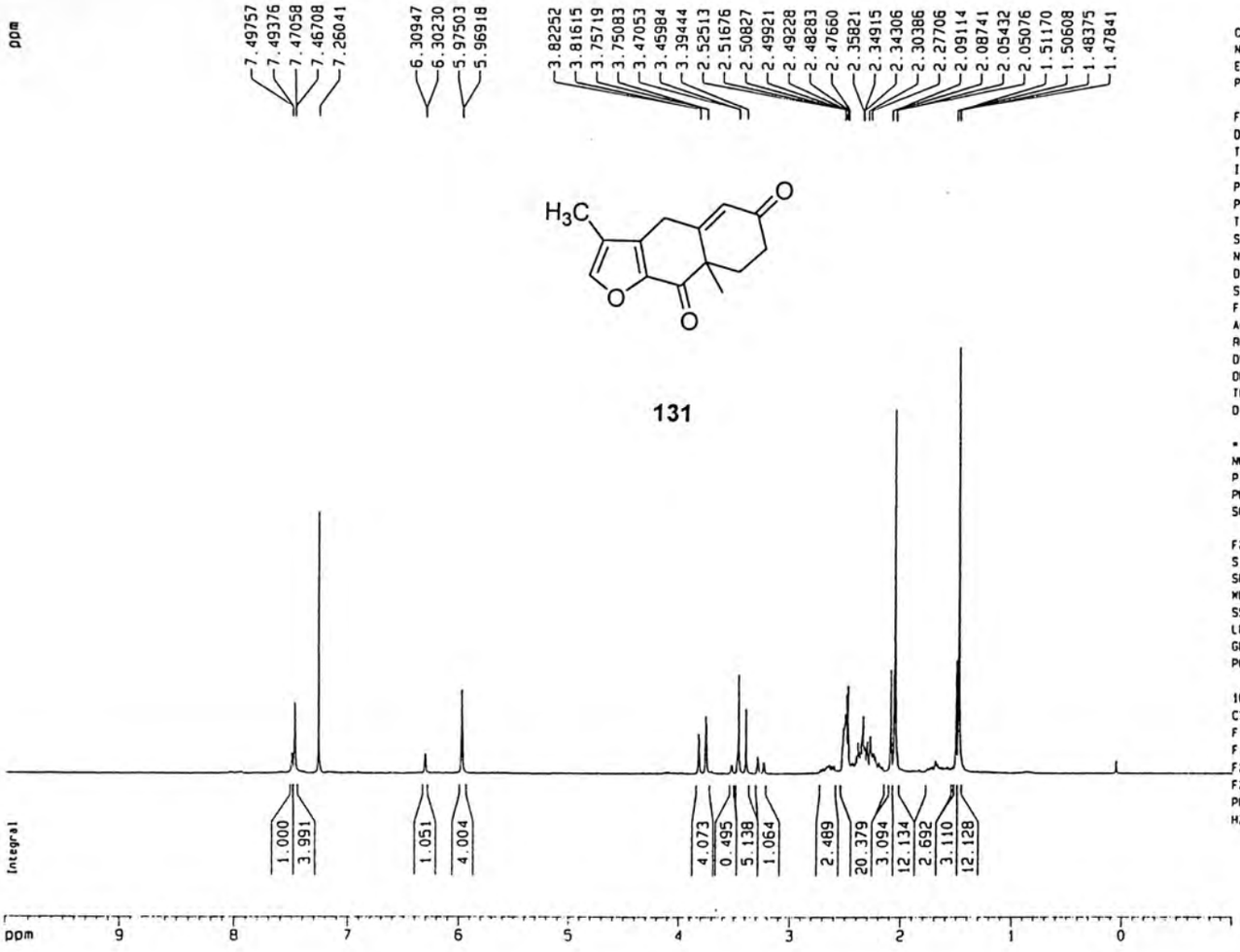
F2 - Acquisition Parameters
Date_ 20000915
Time 7.28
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zgdc
TD 65536
SOLVENT CDCl3
NS 1533
DS 0
SWH 22675.736 Hz
FIDRES 0.346004 Hz
AQ 1.4451188 sec
RG 8192
DW 22.050 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
D11 0.03000000 sec

********** CHANNEL f1 *******
NUC1 13C
P1 3.00 usec
PL1 -6.00 dB
SFO1 75.4745111 MHz

********** CHANNEL f2 *******
CPDPRG2 waltz16
NUC2 1H
PCPD2 100.00 usec
PL2 120.00 dB
PL12 19.00 dB
SFO2 300.1315007 MHz

F2 - Processing parameters
SI 65536
SF 75.4677593 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 1.40

1D NMR plot parameters
CX 23.00 cm
F1P 220.000 ppm
F1 16602.91 Hz
F2P -20.000 ppm
F2 -1509.36 Hz
PPMCM 10.43478 ppm/cm
HZCM 787.48962 Hz/cm



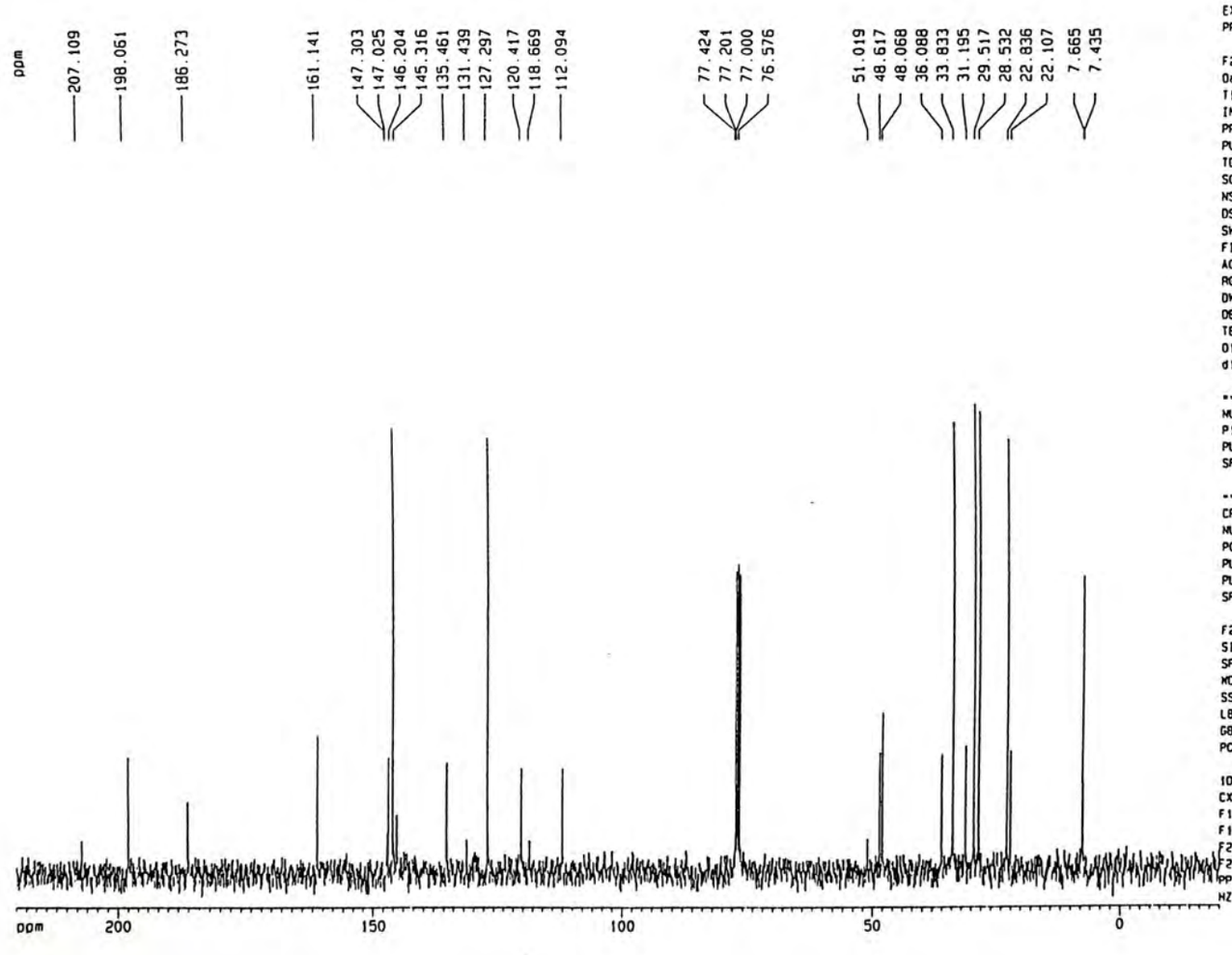
Current Data Parameters
NAME 4p96c1tt8-16
EXPNO 1
PROCNO 1

F2 - Acquisition Parameters
Date_ 20001209
Time 8.39
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 16
DS 0
SWH 8992.806 Hz
FIDRES 0.274439 Hz
AQ 1.8219508 sec
RG 228.1
DW 55.600 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec

---------- CHANNEL f1 -------
NUC1 1H
P1 4.50 usec
PL1 -2.00 dB
SFO1 300.1312000 MHz

F2 - Processing parameters
SI 32768
SF 300.1300057 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 0.60

1D NMR plot parameters
CX 23.00 cm
F1P 10.000 ppm
F1 3001.30 Hz
F2P -1.000 ppm
F2 -300.13 Hz
PPMCM 0.47826 ppm/cm
HZCM 143.54044 Hz/cm



Current Data Parameters
NAME 4p96c1tt8-16
EXPNO 2
PROCNO 1

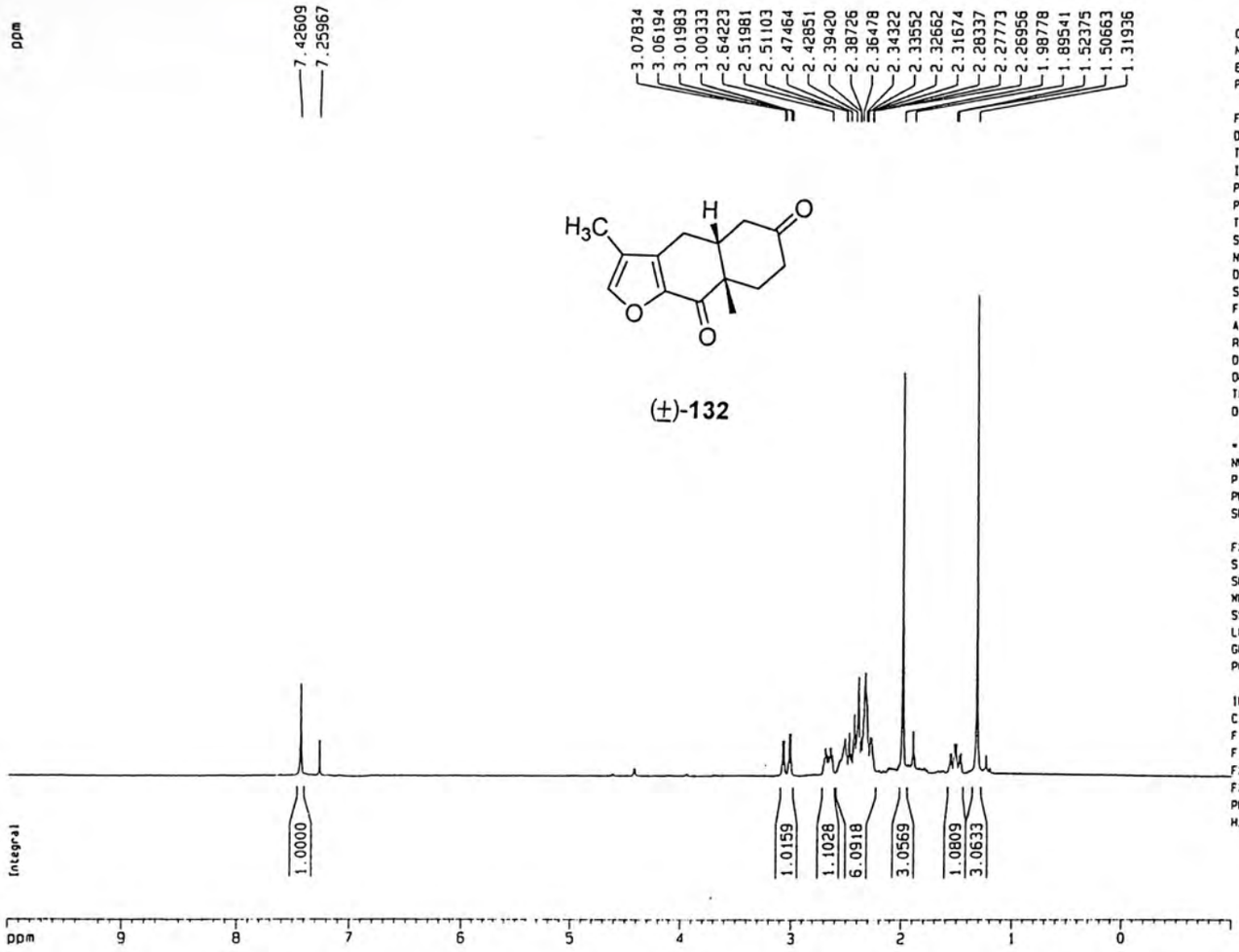
F2 - Acquisition Parameters
Date_ 20001209
Time 8.49
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zgdc
TD 65536
SOLVENT CDCl3
NS 102
DS 0
SWH 22675.736 Hz
FIDRES 0.346004 Hz
AQ 1.4451188 sec
RG 8192
DW 22.050 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
D11 0.03000000 sec

---------- CHANNEL f1 -------
NUC1 13C
P1 3.00 usec
PL1 -6.00 dB
SFO1 75.4745111 MHz

---------- CHANNEL f2 -------
CPDPRG2 waltz16
NUC2 1H
PCPD2 100.00 usec
PL2 120.00 dB
PL12 19.00 dB
SFO2 300.1315007 MHz

F2 - Processing parameters
SI 65536
SF 75.4677541 MHz
WDW EM
SSB 0
LB 3.00 Hz
GB 0
PC 0.60

1D NMR plot parameters
CX 23.00 cm
F1P 220.000 ppm
F1 16602.90 Hz
F2P -20.000 ppm
F2 -1509.36 Hz
PPMCM 10.43478 ppm/cm
HZCM 787.48956 Hz/cm



(±)-**132**

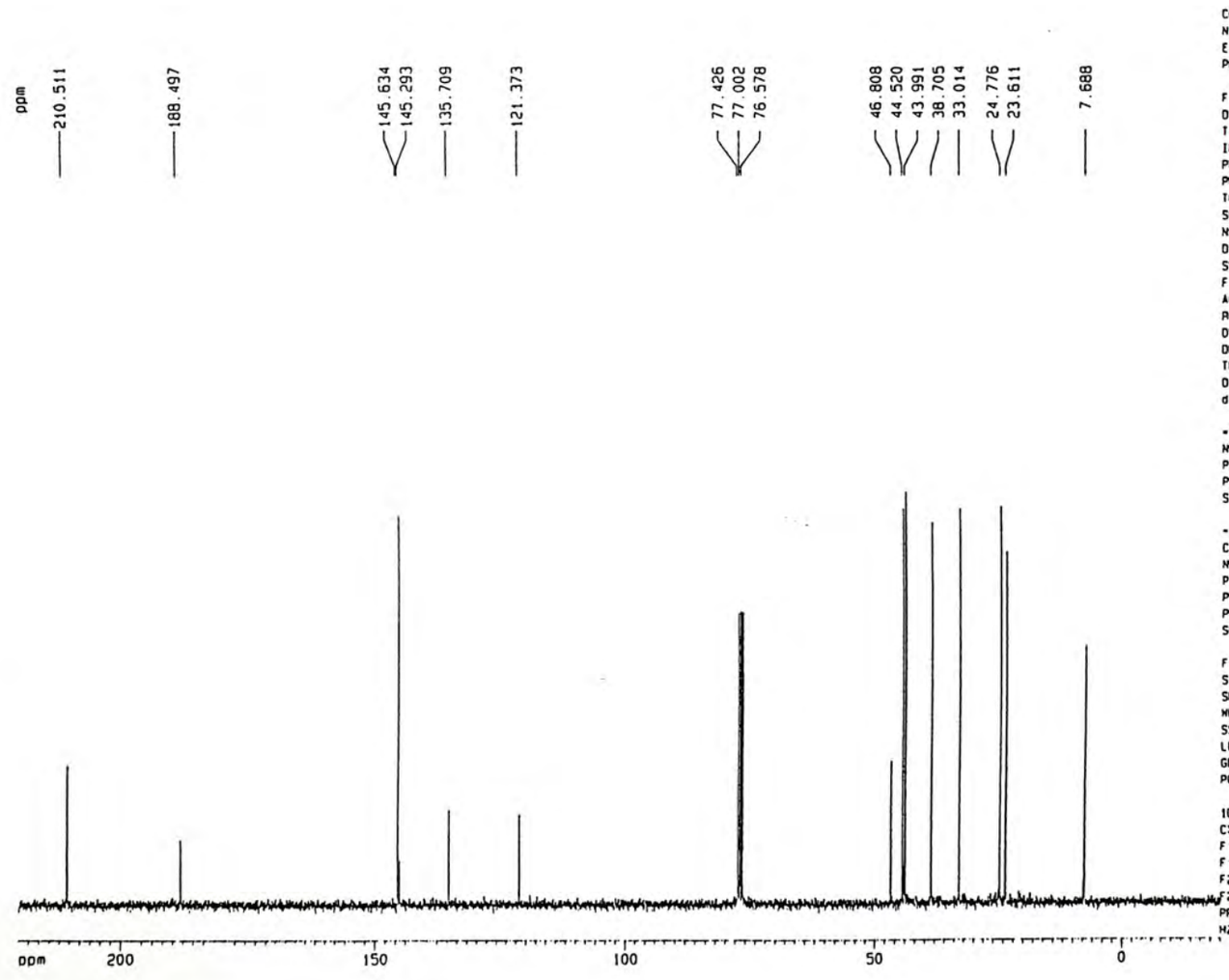
Current Data Parameters
NAME 5o25c2tt16-18
EXPNO 1
PROCNO 1

F2 - Acquisition Parameters
Date_ 20010205
Time 11.28
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 16
DS 0
SWH 8992.806 Hz
FIDRES 0.274439 Hz
AQ 1.8219508 sec
RG 114
DW 55.600 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec

========== CHANNEL f1 =======
NUC1 1H
P1 4.50 usec
PL1 -2.00 dB
SFO1 300.1312000 MHz

F2 - Processing parameters
SI 32768
SF 300.1300060 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

1D NMR plot parameters
CX 23.00 cm
F1P 10.000 ppm
F1 3001.30 Hz
F2P -1.000 ppm
F2 -300.13 Hz
PPMCM 0.47826 ppm/cm
HZCM 143.54044 Hz/cm



Current Data Parameters
NAME 5o25c2tt16-18
EXPNO 2
PROCNO 1

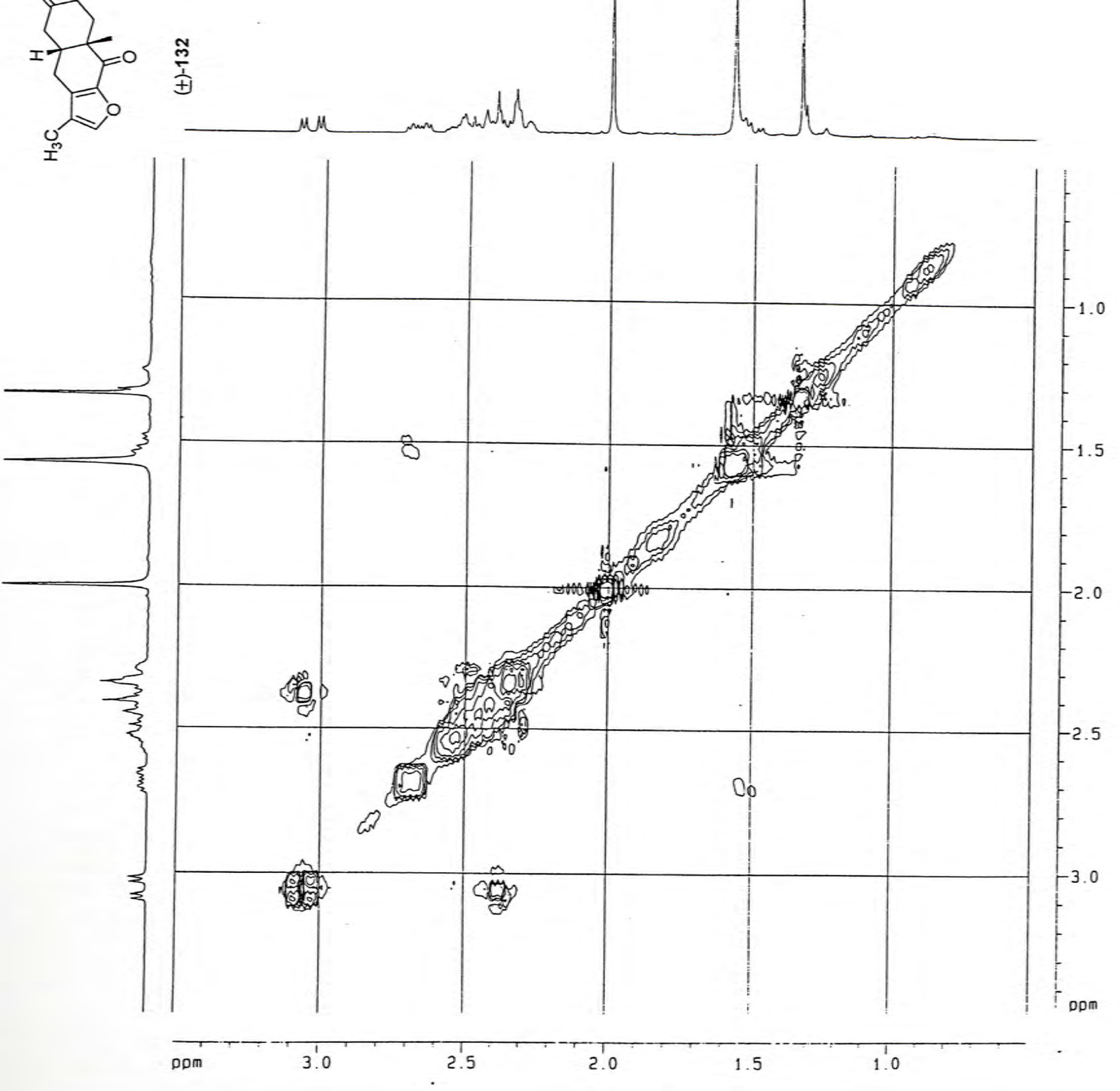
F2 - Acquisition Parameters
Date_ 20010205
Time 11.51
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zgdc
TD 65536
SOLVENT CDCl3
NS 810
DS 0
SWH 22675.736 Hz
FIDRES 0.346004 Hz
AQ 1.4451188 sec
RG 6502
DW 22.050 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
D11 0.03000000 sec

========== CHANNEL f1 =======
NUC1 13C
P1 3.00 usec
PL1 -6.00 dB
SFO1 75.4745111 MHz

========== CHANNEL f2 =======
CPDPRG2 waltz16
NUC2 1H
PCPD2 100.00 usec
PL2 120.00 dB
PL12 19.00 dB
SFO2 300.1315007 MHz

F2 - Processing parameters
SI 65536
SF 75.4677524 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

1D NMR plot parameters
CX 23.00 cm
F1P 220.000 ppm
F1 16602.90 Hz
F2P -20.000 ppm
F2 -1509.36 Hz
PPMCM 10.43478 ppm/cm
HZCM 787.48956 Hz/cm



Current Data Parameters

NAME	2d-ch3diketone
EXPNO	61
PROCNO	1

F2 - Acquisition Parameters

Date_	20010302
Time	0.32
INSTRUM	dqx300
PROBHD	5 mm Dual 13
PULPROG	noesytp
TD	1024
SOLVENT	C6D6
NS	32
DS	16
SWH	2997.602 Hz
FIDRES	2.927346 Hz
AQ	0.1708532 sec
RG	2580.3
DW	166.800 usec
DE	6.00 usec
TE	300.0 K
d0	0.00000300 sec
D1	2.00000000 sec
D8	0.34999999 sec
IN0	0.00016659 sec

********** CHANNEL f1 **********

NUC1	1H
P1	9.30 usec
PL1	-2.00 dB
SF01	300.1313500 MHz

F1 - Acquisition parameters

NDO	2
TD	256
SF01	300.1313 MHz
FIDRES	11.724319 Hz
SW	10.000 ppm

F2 - Processing parameters

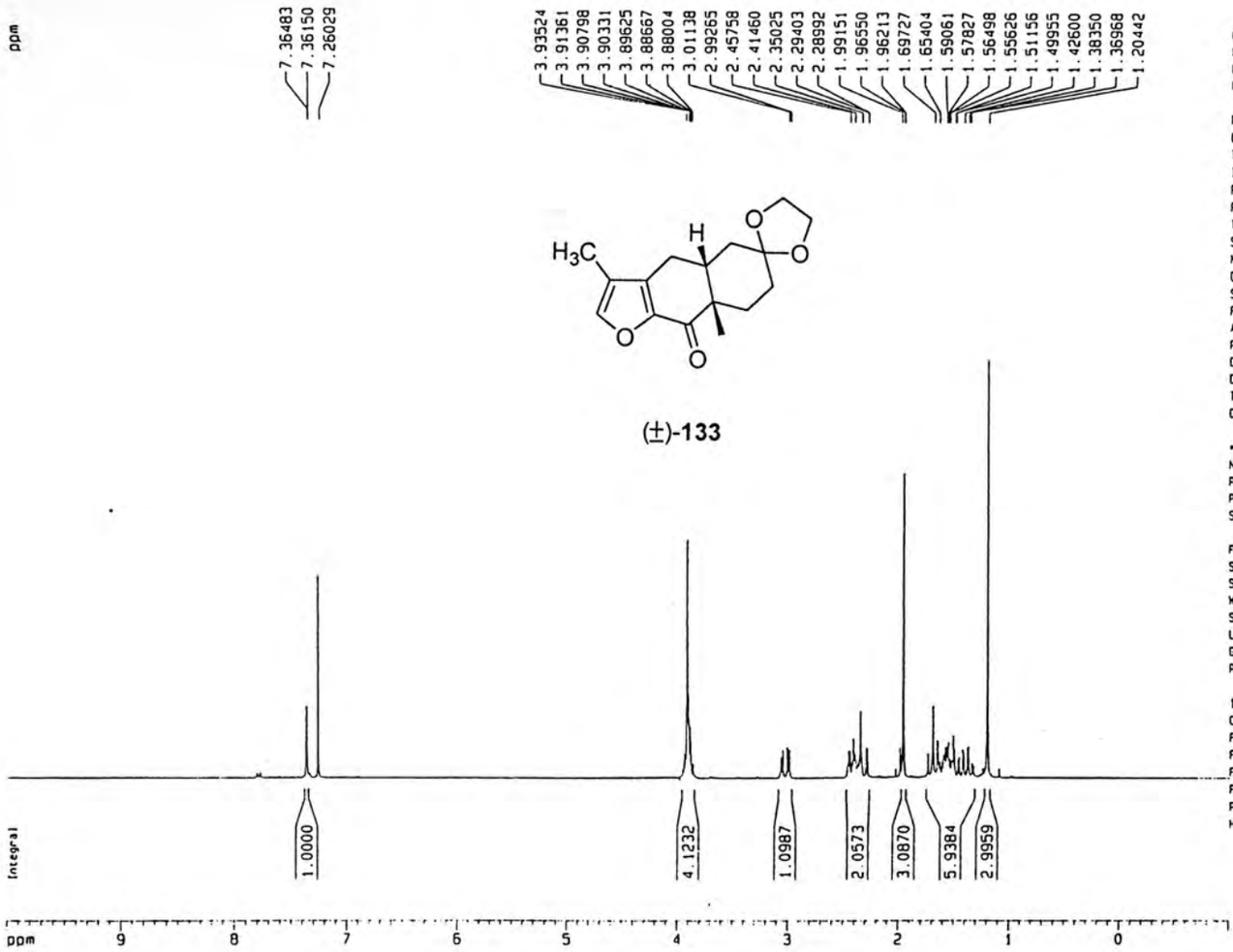
SI	1024
SF	300.1300047 MHz
WDW	SINE
SSB	2
LB	0.00 Hz
GB	0
PC	1.00

F1 - Processing parameters

SI	512
MC2	TPPI
SF	300.1300058 MHz
WDW	SINE
SSB	2
LB	0.00 Hz
GB	0

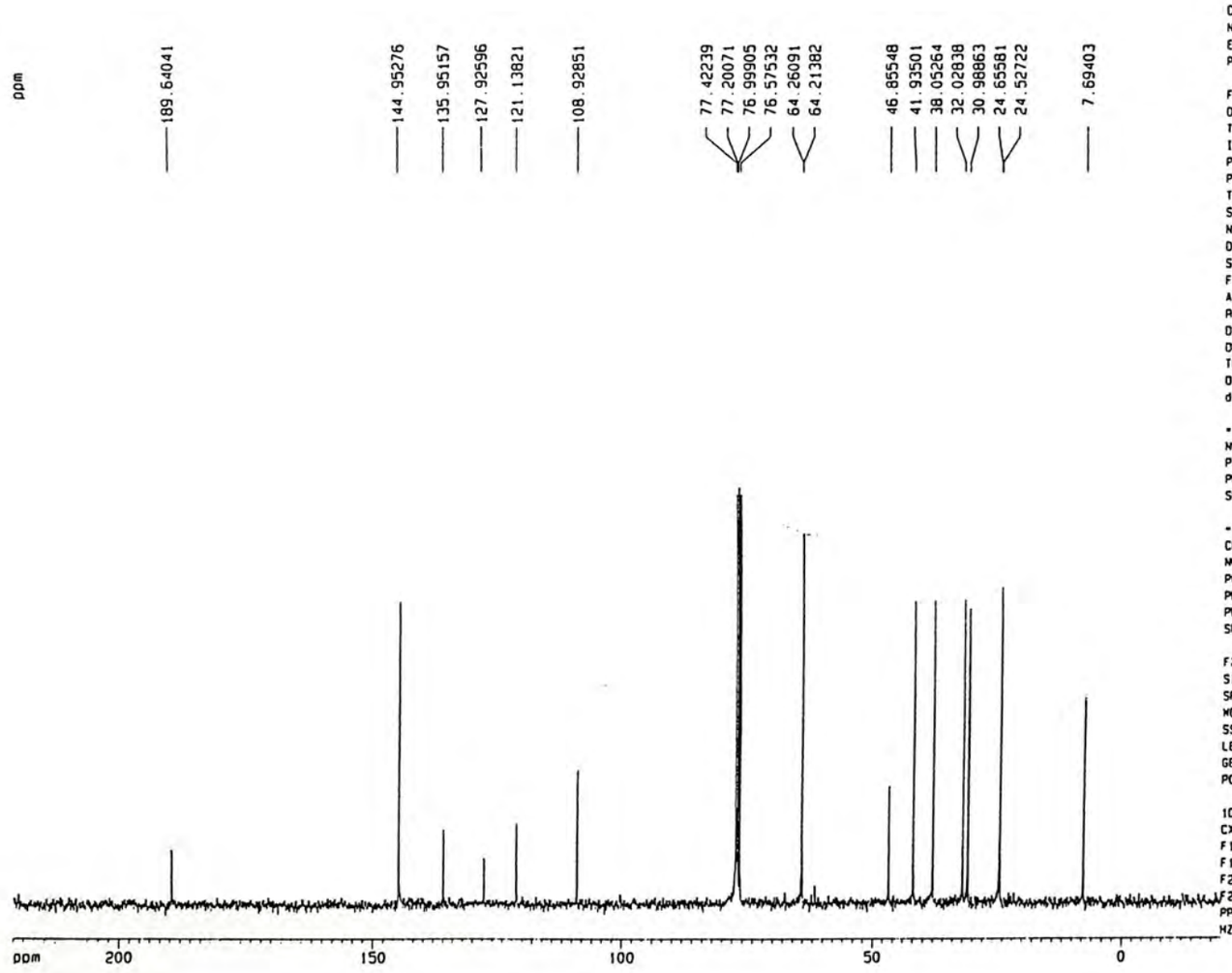
2D NMR plot parameters

CX2	15.00 cm
CX1	15.00 cm
F2PL0	3.497 ppm
F2L0	1049.63 Hz
F2PHI	0.503 ppm
F2HI	150.93 Hz
F1PL0	3.483 ppm
F1L0	1045.26 Hz
F1PHI	0.514 ppm
F1HI	154.21 Hz
F2PPMCM	0.19962 ppm/cm
F2HZCM	59.91300 Hz/cm
F1PPMCM	0.19792 ppm/cm
F1HZCM	59.40322 Hz/cm

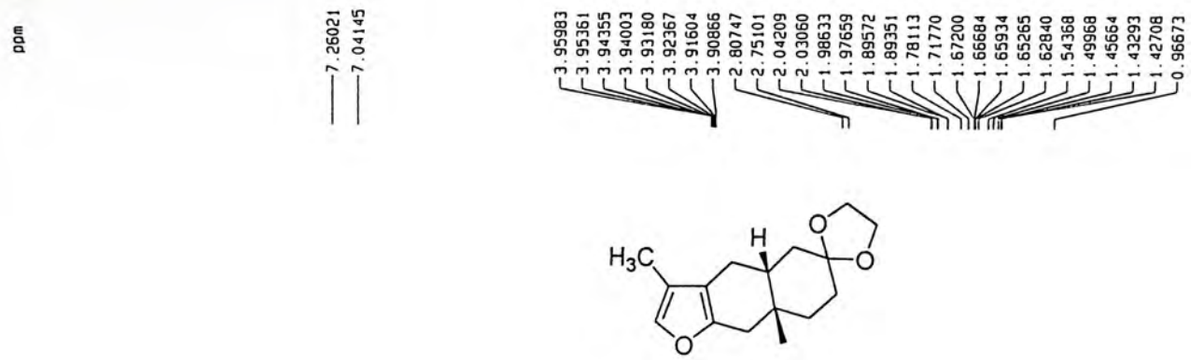


(±)-133

```
Current Data Parameters
NAME          4p100c1tt4-6
EXPNO                    1
PROCNO                   1

F2 - Acquisition Parameters
Date_              20001214
Time                 19.17
INSTRUM              dpx300
PROBHD     5 mm Dual 13
PULPROG                zg
TD                  32768
SOLVENT             CDCl3
NS                      8
DS                      0
SWH             8992.806 Hz
FIDRES          0.274439 Hz
AQ              1.8219508 sec
RG                    114
DW                55.600 usec
DE                 6.00 usec
TE                300.0 K
D1             1.00000000 sec

============ CHANNEL f1 =======
NUC1                   1H
P1                 4.50 usec
PL1               -2.00 dB
SFO1          300.1312000 MHz

F2 - Processing parameters
SI                  32768
SF            300.1300060 MHz
WDW                    EM
SSB                     0
LB                 0.30 Hz
GB                      0
PC                 0.80

1D NMR plot parameters
CX                23.00 cm
F1P              10.000 ppm
F1               3001.30 Hz
F2P              -1.000 ppm
F2               -300.13 Hz
PPMCM          0.47826 ppm/cm
HZCM          143.54044 Hz/cm
```




```
Current Data Parameters
NAME          4p100c1tt4-6
EXPNO                    2
PROCNO                   1

F2 - Acquisition Parameters
Date_              20001214
Time                 19.36
INSTRUM              dpx300
PROBHD     5 mm Dual 13
PULPROG              zgdc
TD                  65536
SOLVENT             CDCl3
NS                    727
DS                      0
SWH            22675.736 Hz
FIDRES          0.346004 Hz
AQ              1.4451188 sec
RG                   4096
DW                22.050 usec
DE                 6.00 usec
TE                300.0 K
D1             1.00000000 sec
D11            0.03000000 sec

============ CHANNEL f1 =======
NUC1                  13C
P1                 3.00 usec
PL1               -6.00 dB
SFO1          75.4745111 MHz

============ CHANNEL f2 =======
CPDPRG2           waltz16
NUC2                   1H
PCPD2            100.00 usec
PL2               120.00 dB
PL12               19.00 dB
SFO2          300.1315007 MHz

F2 - Processing parameters
SI                  65536
SF            75.4677520 MHz
WDW                    EM
SSB                     0
LB                 3.00 Hz
GB                      0
PC                 1.40

1D NMR plot parameters
CX                23.00 cm
F1P             220.000 ppm
F1              16602.90 Hz
F2P             -20.000 ppm
F2              -1509.35 Hz
PPMCM         10.43478 ppm/cm
HZCM          787.48950 Hz/cm
```



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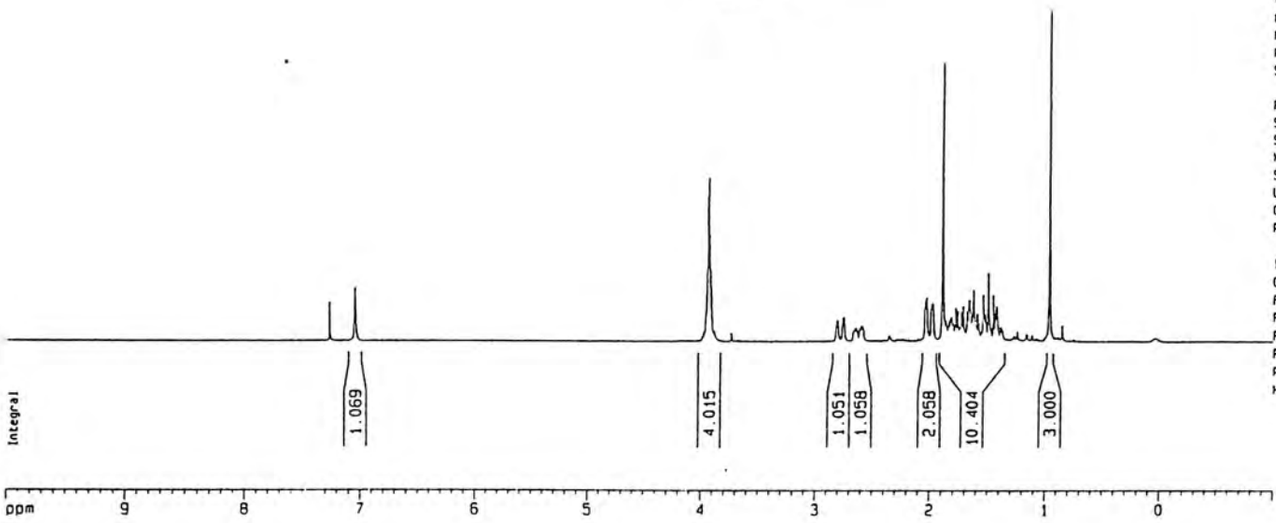
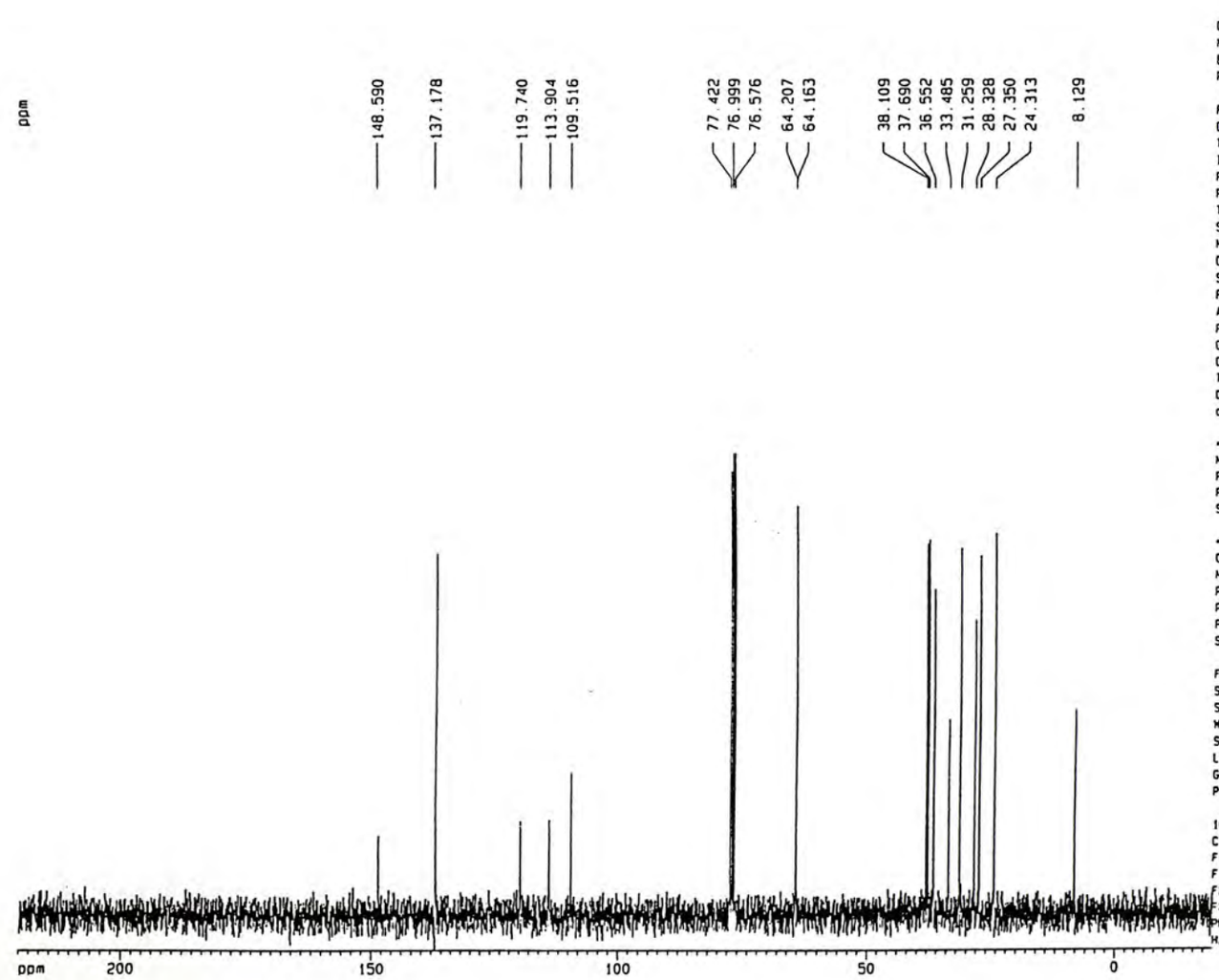
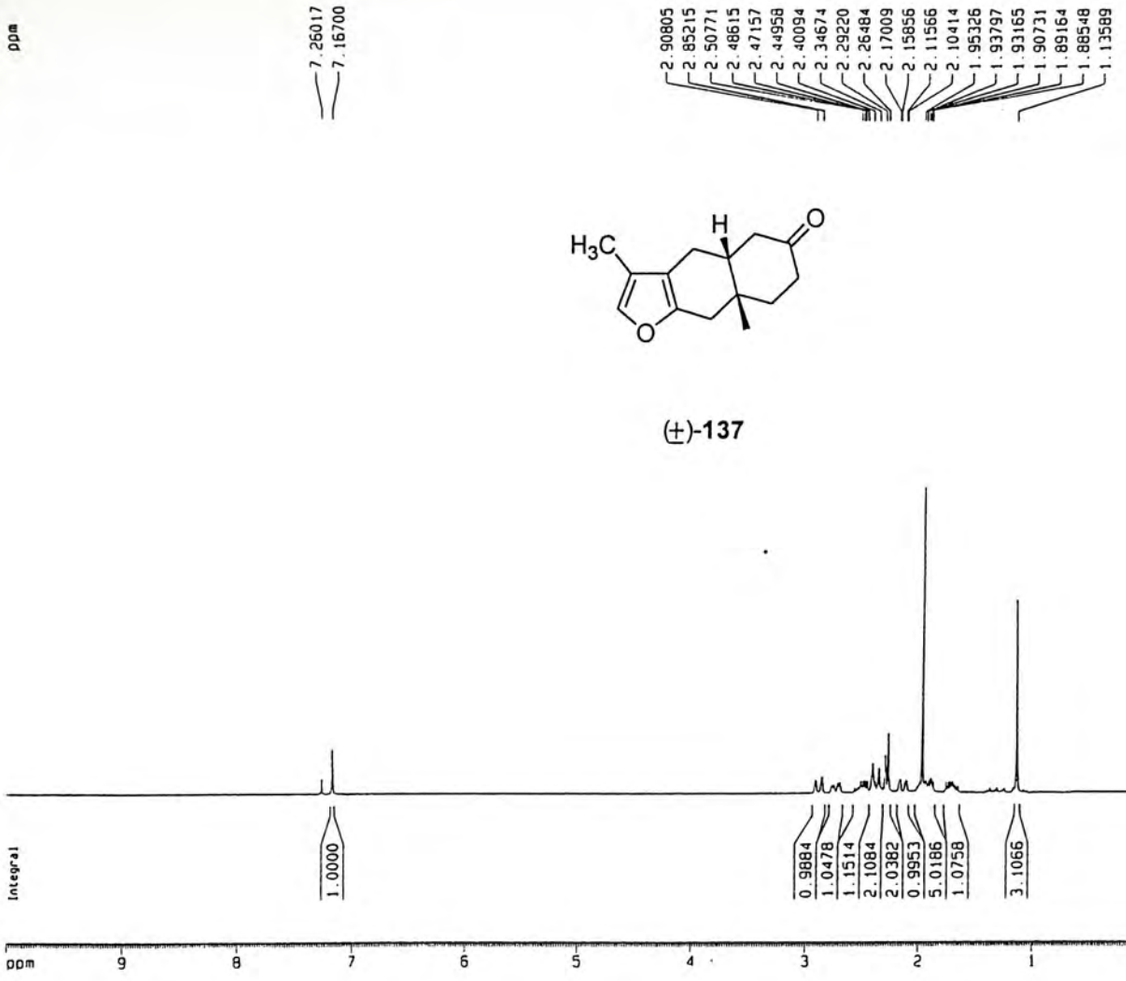



```
Current Data Parameters
NAME            6o8c2tt4-6
EXPNO                    1
PROCNO                   1

F2 - Acquisition Parameters
Date_           20010619
Time                20.32
INSTRUM           dpx300
PROBHD     5 mm Dual 13
PULPROG                zg
TD                  32768
SOLVENT             CDCl3
NS                     16
DS                      0
SWH             8992.806 Hz
FIDRES          0.274439 Hz
AQ              1.8219508 sec
RG                    128
DW                55.600 usec
DE                 6.00 usec
TE                300.0 K
D1              1.00000000 sec

======== CHANNEL f1 ========
NUC1                   1H
P1                 4.50 usec
PL1                -2.00 dB
SFO1          300.1312000 MHz

F2 - Processing parameters
SI                  32768
SF          300.1300060 MHz
WDW                    EM
SSB                     0
LB                 0.30 Hz
GB                      0
PC                   1.00

1D NMR plot parameters
CX                 23.00 cm
F1P               10.000 ppm
F1              3001.30 Hz
F2P               -1.000 ppm
F2              -300.13 Hz
PPMCM           0.47826 ppm/cm
HZCM            143.54044 Hz/cm
```




```
Current Data Parameters
NAME            6o8c2tt4-6
EXPNO                    2
PROCNO                   1

F2 - Acquisition Parameters
Date_           20010619
Time                20.34
INSTRUM           dpx300
PROBHD     5 mm Dual 13
PULPROG             zgdc
TD                  65536
SOLVENT             CDCl3
NS                    161
DS                      0
SWH            22675.736 Hz
FIDRES          0.346004 Hz
AQ              1.4451188 sec
RG                   8192
DW                22.050 usec
DE                 6.00 usec
TE                300.0 K
D1              1.00000000 sec
D11             0.03000000 sec

======== CHANNEL f1 ========
NUC1                   13C
P1                 3.00 usec
PL1                -6.00 dB
SFO1          75.4745111 MHz

======== CHANNEL f2 ========
CPDPRG2            waltz16
NUC2                   1H
PCPD2             100.00 usec
PL2                120.00 dB
PL12               19.00 dB
SFO2          300.1315007 MHz

F2 - Processing parameters
SI                  65536
SF          75.4677503 MHz
WDW                    EM
SSB                     0
LB                 1.00 Hz
GB                      0
PC                   1.40

1D NMR plot parameters
CX                 23.00 cm
F1P               220.000 ppm
F1              16602.90 Hz
F2P               -20.000 ppm
F2              -1509.35 Hz
PPMCM           10.43478 ppm/cm
HZCM            787.46950 Hz/cm
```



(±)-**137**

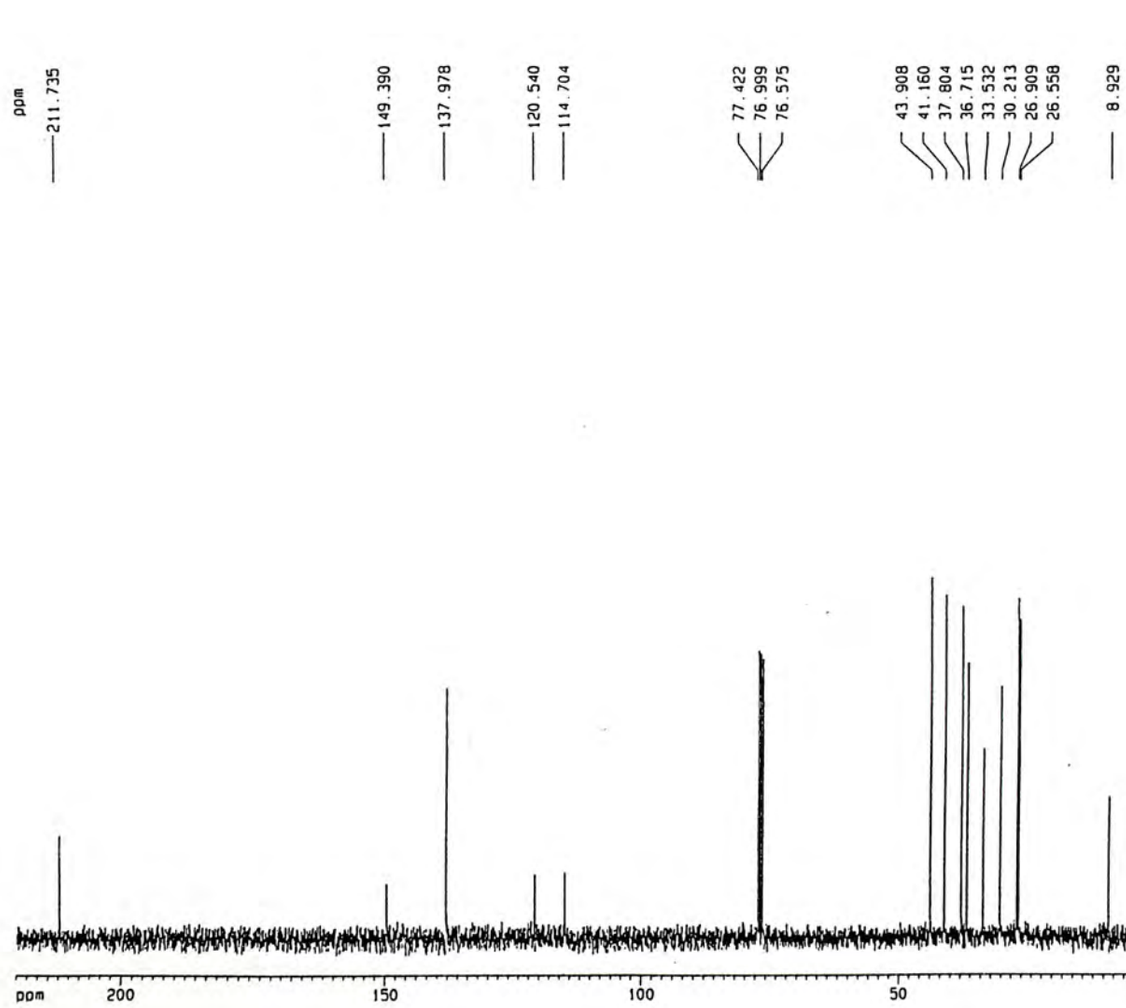
Current Data Parameters
NAME 5p55c1tt10-19
EXPNO 1
PROCNO 1

F2 - Acquisition Parameters
Date_ 20010320
Time 16.52
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zg
TD 32768
SOLVENT CDCl3
NS 8
DS 0
SWH 8992.806 Hz
FIDRES 0.274439 Hz
AQ 1.8219508 sec
RG 114
DW 55.600 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec

********** CHANNEL f1 *******
NUC1 1H
P1 4.50 usec
PL1 -2.00 dB
SFO1 300.1312000 MHz

F2 - Processing parameters
SI 32768
SF 300.1300063 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 0.80

1D NMR plot parameters
CX 23.00 cm
F1P 10.000 ppm
F1 3001.30 Hz
F2P -1.000 ppm
F2 -300.13 Hz
PPMCM 0.47826 ppm/cm
HZCM 143.54044 Hz/cm



Current Data Parameters
NAME 6
EXPNO 2
PROCNO 1

F2 - Acquisition Parameters
Date_ 20010619
Time 20.34
INSTRUM dpx300
PROBHD 5 mm Dual 13
PULPROG zgdc
TD 65536
SOLVENT CDCl3
NS 161
DS 0
SWH 22675.736 Hz
FIDRES 0.346004 Hz
AQ 1.4451188 sec
RG 8192
DW 22.050 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
D11 0.03000000 sec

********** CHANNEL f1 *******
NUC1 13C
P1 3.00 usec
PL1 -6.00 dB
SFO1 75.4745111 MHz

********** CHANNEL f2 *******
CPDPRG2 waltz16
NUC2 1H
PCPD2 100.00 usec
PL2 120.00 dB
PL12 19.00 dB
SFO2 300.1315007 MHz

F2 - Processing parameters
SI 65536
SF 75.4676899 MHz
WDW EM
SSB 0
LB 1.00 Hz
GB 0
PC 1.40

1D NMR plot parameters
CX 23.00 cm
F1P 220.000 ppm
F1 16602.89 Hz
F2P -20.000 ppm
F2 -1509.35 Hz
PPMCM 10.43478 ppm/cm
HZCM 787.48895 Hz/cm